ENGINEERING EXPERIMENT STATION

Georgia Institute of Technology

PROJECT TERMINATION

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PROJECT DIRECTOR: C. E. Blakely

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QUARTERLY TECHNICAL REPORT NO. 1

PROJECT NO. A-418

MUTUAL INTERFERENCE CHARTS FOR A RADIO REPEATER SET

By

C. E. BLAKELY, W. R. FREE,
H. H. JENKINS AND W. M. PEACOCK

- o - o - o - o -

CONTRACT NO. DA-36-039-SC-78243
DEPARTMENT OF THE ARMY PROJECT: 3-24-01-291

- o - o - o - o -

1 NOVEMBER 1958 TO 30 JANUARY 1959

PLACED BY THE U. S. ARMY
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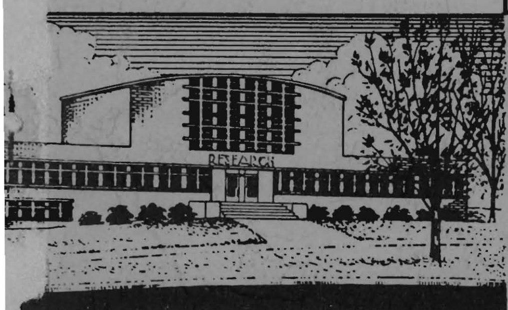

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

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Quarterly Technical Report No. 1, 1 November 1958 to 30 January 1959, 24 pp - 9 illus (Contract DA-36-039-SC-78243) DA Project 3-24-01-291, Unclassified Report

The linear equations and frequency limits used to construct a theoretical Mutual Interference Chart (MIC) for the AN/GRC-19, AN/VRC-14 radio repeater combination are presented.

The first theoretical MIC is also shown.

UNCLASSIFIED
Mutual Interference Charts for a Radio Repeater Set

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ENGINEERING EXPERIMENT STATION
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QUARTERLY TECHNICAL REPORT NO. 1

PROJECT NO. A-418

MUTUAL INTERFERENCE CHARTS FOR A RADIO REPEATER SET

By

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CONTRACT NO. DA-36-039-SC-78243
DEPARTMENT OF THE ARMY PROJECT: 3-24-01-291

- o - o - o - o -

The object of this research is the preparation of a Mutual Interference Chart for the determination of compatible operating frequencies for the AN/GRC-19 and AN/VRC-14.

1 NOVEMBER 1958 TO 30 JANUARY 1959

PLACED BY THE U.S. ARMY
SIGNAL ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

TABLE OF CONTENTS

This report contains 24 pages.

LIST OF FIGURES

LIST OF TABLES

I. PURPOSE

The purpose of this investigation is to determine compatible operating frequencies for the AN/GRC-19 and AN/VRC-14 when operated as a radio repeater.

A theoretical Mutual Interference Chart (MIC), constructed by means of linear equations, is to be used as the basis for this study. These charts will be modified by laboratory and field measurements to further enhance their accuracy. They will then become part of the final report to be used to select operating frequencies.

II. ABSTRACT

The linear equations and frequency limits used to construct a theoretical Mutual Interference Chart (MIC) for the AN/GRC-19, AN/VRC-14 radio repeater combination are presented.

The first theoretical MIC is also shown.

III. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

Mr. W. B. Wrigley visited Fort Monmouth on December 8, 1958 to discuss technical specifications for the Mutual Interference Charts and the availability of test frequencies for field use.

IV. FACTUAL DATA

A. General

The radio repeater described below is used for two-way retransmission of messages in air-to-ground liason. The repeater consists of an AN/GRC-19 and an AN/VRC-14 mounted in a jeep. The former consists of a 1.5- to 20-mc/sec AM transmitter (T-195/GRC-19) and a 1.5- to 32-mc/sec AM radio receiver (R-392/URR), and the latter consists of the RT-67/GRC FM receiver-transmitter combination.

In use the FM receiver and AM transmitter are used simultaneously for transmission in one direction, and will hereafter be referred to as Set A. For transmission in the opposite direction the AM receiver and FM transmitter are used, and will be referred to as Set B.

Any mutual interference that arises in the use of this equipment as a repeater can be associated with either Set A or B in the form of a Mutual Interference Chart (MIC). Since the equipments are used in fixed combinations, one chart can be constructed for Set A and another for Set B.

The theoretical MIC's for the combinations of equipments discussed above are shown as Figures 1, 2 and 3; the large number of R-392/URR third mixer responses are shown separately by means of an overlay. The assumptions involved and the equations used to obtain these charts are discussed in Sections B, C, D and E following.

B. T-195/GRC-19 Spurious Radiations

The T-195/GRC-19 is a servo-tuned AM transmitter which operates over the frequency range of 1.5 to 20 mc/sec. The output frequency is always derived by a series of amplifiers and frequency multipliers from a master oscillator. Measurements conducted on a typical transmitter indicate that only harmonics of the transmitter carrier appear at the antenna terminals over the frequency range 27 to 38.9 mc/sec. Therefore, the interference experienced by the RT-67/GRC because of this transmitter will be identified by the inequality

$$27 \leq nf_o \leq 38.9 \text{ mc/sec.}$$

This interference is shown by the lines that slope from left to right across Figure 1. They are identified on the figure as second harmonic, third harmonic, etc. The width of the harmonic lines are made progressively narrower because of the lower power level in the higher order hramonics.

C. RT-67/GRC Transmitter Spurious Radiations

The spurious radiations of interest from the RT-67/GRC transmitter are satisfied by the inequality

$$1.5 \leq f_{SP} \leq 20 \text{ mc/sec.}$$

Spurious outputs that satisfy this inequality have been observed, and are related to the crystal oscillators, reactance tube oscillators and the receiver i-f.

Table I is a list of the spurious radiations due to the local oscillator crystals which are used to derive the operating frequency. The frequencies above 20 mc/sec do not cause trouble but are included for use in calculating R-392/URR radio receiver spurious responses in Section D.

In addition to the crystal fundamental harmonic frequencies which are radiated from the RT-67/GRC transmitter, the output of the reactance tube modulator is also radiated. This is a constant output on each band of the transmitter and varies from 4.45 mc/sec near the low end of the band to 5.45 mc/sec at the high end of the band. These are shown on Figure 2 as sloping lines between these two frequency limits.

An output which is related to the receiver i-f frequency by

$$f_{SP} = F_{\substack{\text{reactance}\\ \text{tube osc.}}} - f_{\text{receiver}_{i-f}}$$

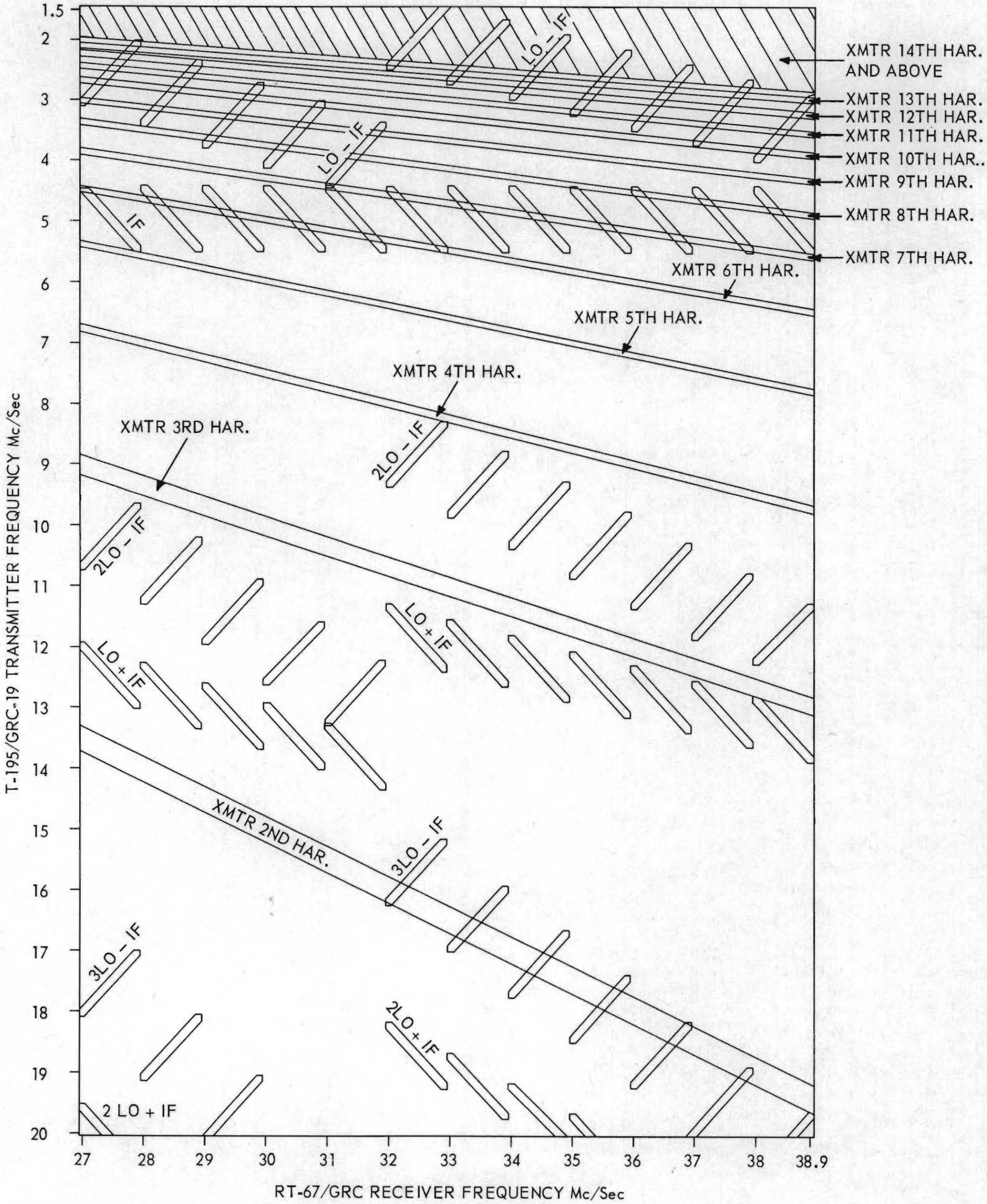

Figure 1. Mutual Interference Chart for the T-195/GRC-19 -- RT-67/GRC Transmitter Receiver Combination.

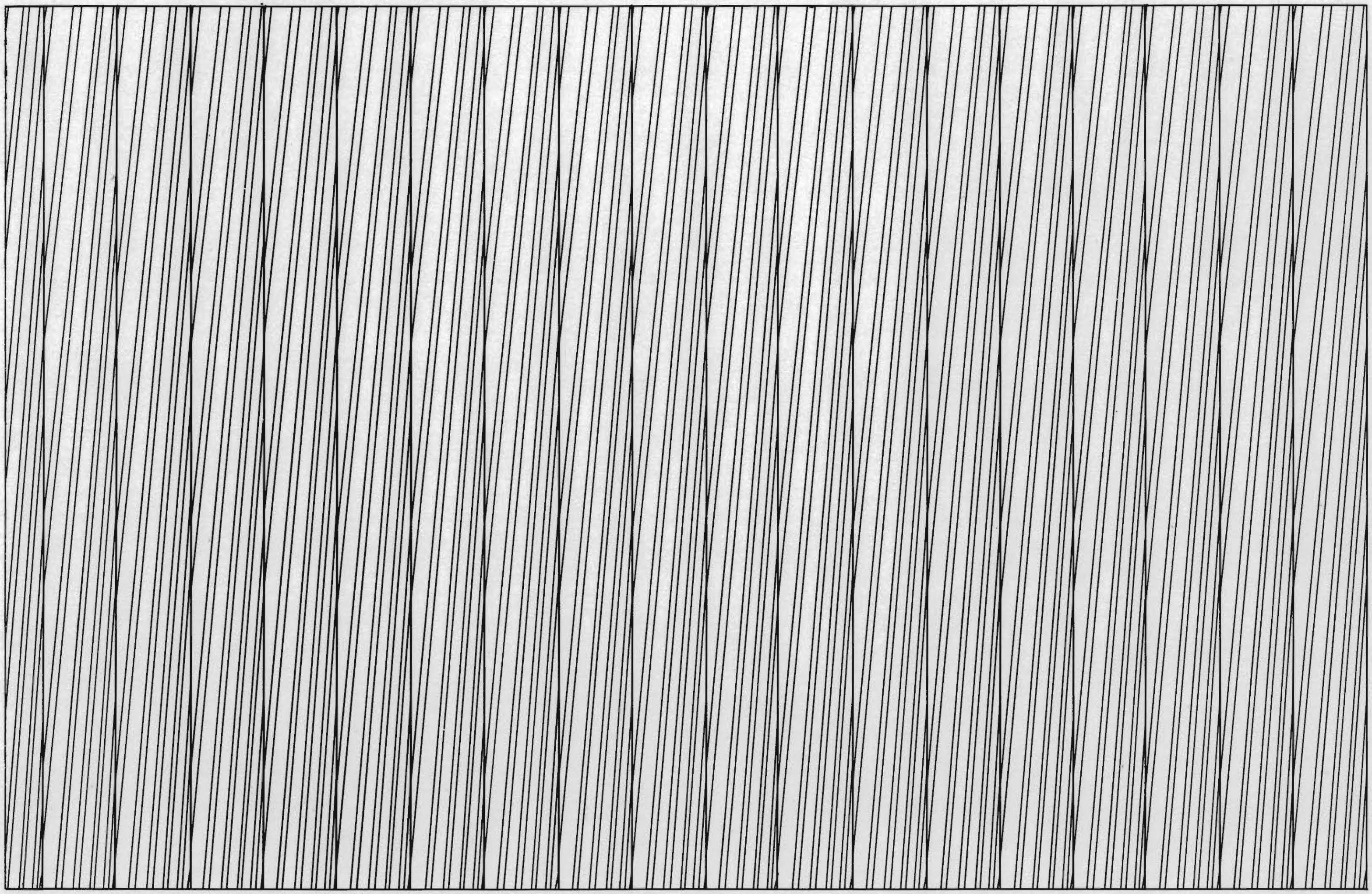

Figure 3. Mutual Interference Chart for the RT-67/GRC -- R-392/URR Transmitter - Receiver (Third Mixer Responses Only).

is also found. These radiations are constant for every band of the transmitter and appear 1.4 mc/sec below the reactance tube oscillator frequency. The interference related to this oscillator slopes from left to right across the 3.05- to 4.05-mc/sec band.

TABLE I

SPURIOUS RADIATIONS OF THE RT-67/GRC TRANSMITTER
DUE TO THE CRYSTAL OSCILLATORS

Tuning Range (Mc/Sec)	Harmonic of Local Oscillator 1	2	3	4
27 - 27.9	7.516666	15.15	22.50*	30.0666
28.28.9	7.850	15.70	23.55*	31.400
29 - 29.9	8.18333	16.36	24.55*	32.733
30 - 30.9	8.516666	17.03	25.55*	34.066
31 - 31.9	8.850	17.700	26.55	35.400
32 - 32.9	6.8875	13.7750	20.6625	27.55*
33 - 33.9	7.1375	14.2750	21.4125	28.55*
34 - 34.9	7.3875	14.7750	22.1625	29.55*
35 - 35.9	7.8875	15.7750	23.6625	30.55*
36 - 36.9	7.8875	15.7759	23.6625	31.55*
37 - 37.9	8.1375	16.2750	24.4125	32.55*
38 - 38.9	9.3875	16.7750	25.1625	33.55*

* Injection Frequency

The crystal local oscillator outputs are shown as vertical lines on Figure 2 and are identified by Table I.

D. R-392/URR Spurious Responses

The R-392/URR is triple conversion receiver from 1.5- to 8-mc/sec and dual conversion from 8- to 32-mc/sec. The receiver is changed from triple to dual conversion by bypassing the first mixer. There are three sets of spurious responses, one for each mixer, defined by the following inequality:

$$27 \leq |p\ f_{LO} \pm f_{IF}| \leq 38.9$$

or

$$27 \leq f_{SP} \leq 38.9 \text{ mc/sec}$$

where p is any integer. The local oscillator crystals for the first two mixers are listed in Table II and the spurious responses calculated by the above equation, using these crystal frequencies, are shown in Tables III and IV.

The third mixer spurious responses are determined by the same equation for each 1-mc/sec frequency band; therefore its spurious response pattern is repeated each time a new band is switched. Responses at the low and high end of the band are defined by:

$$27 \leq f_{SP_{LOW}} \leq 38.9$$

and

$$27 \leq f_{SP_{HIGH}} \leq 38.9$$

respectively where:

$$f_{SP_{LOW}} = |p\ 3.455 \pm .455|$$

$$f_{SP_{HIGH}} = |p\ 2.455 \pm .455|$$

are the low and high ends of each 1-mc/sec band respectively. Since the frequency range is bounded to a 12-mc/sec interval, the range of p is bounded between 8 and 16 inclusive. Table V shows the third mixer calculated spurious responses for each 1-mc/sec range of the R-392/URR.

TABLE II

LOCAL OSCILLATOR FUNDAMENTAL FREQUENCIES FOR THE R-392/URR RECEIVER

1st Crystal Oscillator (Mc/Sec)	Band (Mc/Sec)
9	5 - 1, 6 - 7
8	1 - 2, 5 - 6
10	2 - 3, 7 - 8
12.6	3 - 4
7	4 - 5
2nd Crystal Oscillator (Mc/Sec)	**Band (Mc/Sec)**
12	5 - 1, 1 - 2 9 - 10, 21 - 22
15	2 - 3, 12 - 13
6.2	3 - 4
14	4 - 5, 11 - 12, 25 - 26
8	5 - 6, 13 - 14
9	6 - 7, 15 - 16 , 24 - 25
10	7 - 8, 17 - 18, 27 - 28
11	8 - 9, 19 - 20, 30 - 31
13	10 - 11, 23 - 24
8.5	14 - 15
11.333	31 - 32
10.667	29 - 30
10.333	28 - 29
9.667	26 - 27
12.5	22 - 23
11.5	20 - 21
10.5	18 - 19
9.5	16 - 17

TABLE III

CALCULATED FIRST MIXER RESPONSES FOR THE R-392/URR RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3	4	5	6	7
1.0		8	8	+ 9			33				
		8	8	- 9					31		
		8	8	+ 10			34				
	2.0	8	8	- 10					30		
2		10	10	+ 12		32					
		10	10	- 12				28	38		
		10	10	+ 13		33					
	3	10	10	- 13				27	37		
3		12.6	12.6	+ 15.6	28.2						
		12.6	12.6	- 15.6				34.8			
		12.6	12.6	+ 16.6	29.2						
	4	12.6	12.6	- 16.6				33.8			
4		7	7	+ 11			32				
		7	7	- 11						31	38
		7	7	+ 12			33				
	5	7	7	- 12						30	37
5		8	8	+ 13		29	37				
		8	8	- 13					27	35	
		8	8	+ 14		30	38				
	6	8	8	- 14						34	
6		9	9	+ 15		33					
		9	9	- 15					30		
		9	9	+ 16		34					
	7	9	9	- 16					29	38	
7		10	10	+ 17	27	37					
		10	10	- 17					33		
		10	10	+ 18	28	38					
	8	10	10	- 18					32		

TABLE IV

CALCULATED SECOND MIXER RESPONSES FOR THE R-392/URR RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3	4	5	6
1		12	12	+ 3		27	39			
		12	12	- 3			33*			
		12	12	+ 2		26	38			
	2	12	12	- 2			34*			
2		15	15	+ 3		33				
		15	15	- 3		27				
		15	15	+ 2		32				
	3	15	15	- 2		28				
3		6.2	18.6	+ 3				27.8	34	
		6.2	18.6	- 3					28	34.2
		6.2	18.6	+ 2				26.8	33	
	4	6.2	18.6	- 2					29	35.2
4		14	14	+ 3		31*				
		14	14	- 3						
		14	14	+ 2		30*				
	5	14	14	- 2						
5		8	8	+ 3			27*	35*		
		8	8	- 3				29*	37*	
		8	8	+ 2			26*	34*		
	6	8	8	- 2				30*	38*	

* Same frequency as first mixer responses.

(Continued)

TABLE IV (Continued)

CALCULATED SECOND MIXER RESPONSES FOR THE R-392/URR RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of: 1	2	3	4	5	6
6		9	9	+ 3			30*	39*		
		9	9	- 3				33*		
		9	9	+ 2			29*	38*		
	7	9	9	- 2				34*		
7		10	10	+ 3			33*			
		10	10	- 3			27*	37*		
		10	10	+ 2			32*			
	8	10	10	- 2			28*	38*		
8		11	11	+ 3			36			
		11	11	- 3			30			
		11	11	+ 2			35			
	9	11	11	- 2			31			
9		12	12	+ 3		27	39			
		12	12	- 3			33			
		12	12	+ 2			38			
	10	12	12	- 2			34			
10		13	13	+ 3		29				
		13	13	- 3			36			
		13	13	+ 2		28				
	11	13	13	- 2			37			
11		14	14	+ 3		31				
		14	14	- 3						
		14	14	+ 2		30				
	12	14	14	- 2						

* Same frequency as first mixer responses.

(Continued)

TABLE IV (Continued)

CALCULATED SECOND MIXER RESPONSES FOR THE R-392/URR RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3	4	5	6
12		15	15	+ 3		33				
		15	15	- 3		27				
		15	15	+ 2		32				
	13	15	15	- 2		28				
13		8	16	+ 3			27	35		
		8	16	- 3				29	37	
		8	16	+ 2				34		
	14	8	16	- 2				30	38	
14		8.5	17	+ 3			28.5	37		
		8.5	17	- 3				31		
		8.5	17	+ 2			27.5	36		
	15	8.5	17	- 2				32		
15		9	18	+ 3			30	39		
		9	18	- 3				33		
		9	18	+ 2			29	38		
	16	9	18	- 2				34		
16		9.5	19	+ 3			31.5			
		9.5	19	- 3				35		
		9.5	19	+ 2			30.5			
	17	9.5	19	- 2				36		
17		10	20	+ 3			33			
		10	20	- 3			27	37		
		10	20	+ 2			32			
	18	10	20	- 2			28	38		

(Continued)

TABLE IV (Continued)

CALCULATED SECOND MIXER RESPONSES FOR THE R-392/URR RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3	4	5	6
18		10.5	21	+ 3			34.5			
		10.5	21	- 3			28.5			
		10.5	21	+ 2			33.5			
	19	10.5	21	- 2			29.5			
19		11	22	+ 3			36			
		11	22	- 3			30			
		11	22	+ 2			35			
	20	11	22	- 2			31			

TABLE V

CALCULATED THIRD MIXER RESPONSES FOR EACH ONE MC/SEC BAND ON THE R-392/URR RECEIVER

p	$\pm f_{IF}$ (Mc/Sec)	$f_{SP_{LOW}}$ (Mc/Sec)	$f_{SP_{HIGH}}$ (Mc/Sec)
8	+	28.095	20.09
	-	27.18	19.185
9	+	31.55	22.55
	-	30.64	21.64
10	+	35.005	25.005
	-	34.095	24.095
11	+	38.46	27.460
	-	37.55	26.55
12	+	41.915	29.915
	-	41.005	29.005
13	+	45.37	32.37
	-	44.460	31.460
14	+	48.825	34.825
	-	47.915	33.915
15	+	52.28	37.280
	-	51.37	36.370
16	+	55.735	39.735
	-	54.825	38.825

E. RT-67/GRC Receiver Spurious Responses

The receiver section of the RT-67/GRC uses the same crystal frequencies as the transmitter section; therefore, the crystal frequencies and their first few harmonics, as listed in Table I, can be used to calculate the receiver spurious responses. These spurious responses must be within the limits of the following inequalities:

$$1.5 \leq |p\, f_{LO} \pm f_{IF}| \leq 20$$

or

$$1.5 \leq f_{SP} \leq 20 \text{ mc/sec.}$$

These limits are determined by the tuning range of the T-195/GRC-19 transmitter. On the theoretical MIC the second harmonic of this transmitter is considered only as co-channel interference and the assumption is made that the second harmonic amplitude is not sufficient to cause interference at a spurious response frequency of the receiver. If field and laboratory test data show this assumption to be in error, the MIC will be modified to include these spurious responses.

The spurious responses defined by the above equation are shown as short diagonal lines on Figure 1 and are tabulated in Table VI.

The first i-f of this receiver is tunable from 4.45 to 5.45 mc/sec over each 1-mc/sec frequency band; therefore the i-f responses are shown by sloping lines from 4.45 to 5.45 mc/sec on Figure 1.

TABLE VI

CALCULATED SPURIOUS RESPONSES FOR THE RT-67/GRC RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3
27		7.516666	22.50	+	11.967	19.58	
		7.516666	22.50	-	3.067	10.68	18.05
		7.516666	22.50	+	12.967		
	27.9	7.516666	22.50	-	2.067	9.68	16.05
28		7.850	23.55	+	12.3		
		7.850	23.55	-	3.4	11.25	19.1
		7.850	23.55	+	13.3		
	28.9	7.850	23.55	-	2.4	10.25	18.1
29		8.18333	24.55	+	12.633		
		8.18333	24.55	-	3.7333	11.91	
		8.18333	24.55	+	13.622		
	29.9	8.18333	24.55	-	3.733	10.91	19.1
30		8.516666	25.55	+	12.96		
		8.516666	25.55	-	4.066	12.58	
		8.516666	25.55	+	13.96		
	30.9	8.516666	25.55	-	3.066	11.58	
31		8.850	26.55	+	13.3		
		8.850	26.55	-	4.4		
		8.850	26.55	+	14.3		
	31.9	8.850	26.55	-	3.4	12.25	
32		6.8875	27.55	+	11.3375	18.225	
		6.8875	27.55	-	2.4375	9.325	16.21
		6.8875	27.55	+	12.3375	19.225	
	32.9	6.8875	27.55	-		8.325	15.21

(Continued)

TABLE VI (Continued)

CALCULATED SPURIOUS RESPONSES FOR THE RT-67/GRC RECEIVER

Tuning Range Low End (Mc/Sec)	Tuning Range High End (Mc/Sec)	f_{LO} (Mc/Sec)	Injection Frequency (Mc/Sec)	$\pm f_{IF}$ (Mc/Sec)	Frequency of Spurious Responses in Mc/Sec for p values of 1	2	3
33		7.1375	28.55	+	11.5875	18.725	
		7.1375	28.55	-	2.6875	9.825	16.9625
		7.1375	28.55	+	12.5875	19.725	
	33.9	7.1375	28.55	-		8.825	15.9625
34		7.3875	29.55	+	11.8375	19.225	
		7.3875	29.55	-	2.9375	10.325	17.7125
		7.3875	29.55	+	12.8375		
	34.9	7.3875	29.55	-		9.325	16.7125
35		7.6375	30.55	+	12.0875	19.7175	
		7.6375	30.55	-	3.1875	10.8175	18.455
		7.6375	30.55	+	13.0875		
	35.9	7.6375	30.55	-	3.1875	9.8175	17.455
36		7.8875	31.55	+	12.3375		
		7.8875	31.55	-	3.4375	11.325	19.2125
		7.8875	31.55	+	13.3375		
	36.9	7.8875	31.55	-	2.4375	10.325	18.2125
37		8.1375	32.55	+	12.5875		
		8.1375	32.55	-	3.6875	11.825	19.9625
		8.1375	32.55	+	13.5875		
	37.9	8.1375	32.55	-	2.6875	10.825	18.9625
38		8.3875	33.55	+	12.8375		
		8.3875	33.55	-	3.9375	12.325	
		8.3875	33.55	+	13.8375		
	38.9	8.3875	33.55	-	2.9375	11.325	19.7125

V. CONCLUSIONS

Only general conclusions based on observation of the theoretical MIC can be drawn at this time. This chart seems to indicate that the higher T-195/GRC-19 frequencies are to be preferred in general. All frequencies are equally good for the RT-67/GRC transmitter.

VI. PROGRAM FOR NEXT INTERVAL

Laboratory type tests, to obtain experimental data for modifying the theoretical MIC, will be initiated. These tests will be performed with the respective equipments coupled together through attenuators. Thus with a transmitter operating, the receiver will be tuned through its frequency range to determine the frequencies where interference is expected to occur in the field.

VIII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Charles E. Blakely	Project Director Research Engineer	20%
William R. Free	Assistant Research Engineer	10%
Herndon H. Jenkins	Assistant Research Engineer	10%
Walker M. Peacock	Student Assistant	30%

The background and qualifications of these men are presented in the following paragraphs.

This project is under the direction of Mr. Blakely. He holds the degree of M.S. in E.E. from the University of Tennessee and is currently pursuing studies toward a Ph.D. in that field from the Georgia Institute of Technology. He has previously been associated with the Engineering Experiment Station, University of Tennessee for 3 years; Edenfield Electric Corporation, Oak Ridge, Tennessee; Carbon Carbide Chemical Corporation, Oak Ridge, Tennessee; Radio Station WUCT, Knoxville, Tennessee; and has been associated with various research projects at Georgia Tech for over two years.

Mr. Free holds a B.S. degree in Electrical Engineering from Georgia Tech and is currently pursuing graduate work toward an M.S. degree in the same field. His previous professional experience includes three years as Development Engineer for Sperry Gyroscope Company and one year in crystal oscillator development on another project at Georgia Tech. He served three years as an Electronic Technician in the U. S. Coast Guard.

Mr. Jenkins holds the degree of B.S. in E.E. from the Georgia Institute of Technology. He attended graduate school at Johns Hopkins University and is currently working on an M.S. at the Georgia Institute of Technology. He has previously been associated with the Johns Hopkins University Applied Physics Laboratory.

Mr. Peacock is an undergraduate at the Georgia Institute of Technology. He served 3 years as an Electronics Technician in the U. S. Navy. He has been employed as a technician on vari[illegible] since 1956.

Respectfully submitted:

C. E. Blakely

C. E. Blakely
Project Director

Approved:

W B Wrigley

W. B. Wrigley, Head
Communications Branch
of the
Physical Sciences Division

QUARTERLY TECHNICAL REPORT NO. 2

PROJECT NO. A-418

MUTUAL INTERFERENCE CHARTS FOR A RADIO REPEATER SET

By

C. E. BLAKELY and W. M. PEACOCK

DJ✓

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CONTRACT NO. DA-36-039-SC-78243
DEPARTMENT OF THE ARMY PROJECT: 3-24-01-291

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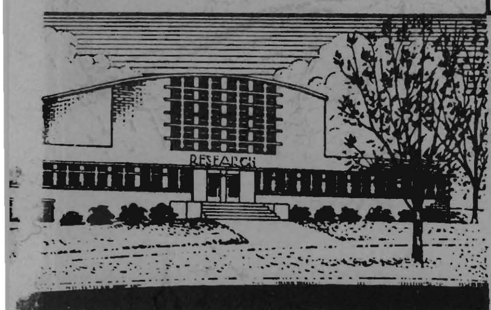
1 FEBRUARY 1959 TO 30 APRIL 1959

PLACED BY THE U. S. ARMY
SIGNAL ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY



Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

AD____Accession No.________
Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia

Experimental Mutual Interference Charts for the AN/GRC-19, AN/VRC-14 radio repeater combination are presented. These charts were constructed for 20 decibels coupling between receiver and transmitter antennas.

The experimental MIC's agree well with the theoretical charts published in Quarterly Technical Report No. 1. A receiver-to-receiver chart was added to show the interference caused by receiver local oscillator radiation.

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ENGINEERING EXPERIMENT STATION
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Atlanta, Georgia

QUARTERLY TECHNICAL REPORT NO. 2

PROJECT NO. A-418

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By

C. E. BLAKELY and W. M. PEACOCK

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CONTRACT NO. DA-36-039-SC-78243
DEPARTMENT OF THE ARMY PROJECT: 3-24-01-291

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The object of this research is the preparation of a Mutual Interference Chart for the determination of compatible operating frequencies for the AN/GRC-19 and AN/VRC-14.

1 FEBRUARY 1959 TO 30 APRIL 1959

PLACED BY THE U. S. ARMY
SIGNAL ENGINEERING LABORATORIES
FORT MONMOUTH, NEW JERSEY

TABLE OF CONTENTS

This report contains 16 pages.

LIST OF FIGURES

I. PURPOSE

The purpose of this investigation is to determine compatible operating frequencies for the AN/GRC-19 and AN/VRC-14 Radio Sets when operated as a radio repeater.

Theoretical Mutual Interference Charts (MIC's), constructed by means of linear equations, are to be used as the basis for this study. These charts, modified by laboratory and field measurements to further enhance their accuracy, will then become part of the final report to be used in selecting operating frequencies.

II. ABSTRACT

Experimental Mutual Interference Charts for the AN/GRC-19, AN/VRC-14 radio repeater combination are presented. These charts were constructed for 20 decibels coupling between receiver and transmitter antennas.

The experimental MIC's agree well with the theoretical charts published in Quarterly Technical Report No. 1. A receiver-to-receiver chart was added to show the interference caused by receiver local oscillator radiation.

III. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

Mr. Weitz, Mr. Gottfried, Mr. Chappel and Mr. Hecker of USASRDL visited Georgia Tech on February 4 and 5. Some of the results and the progress to date were discussed.

Mr. W. R. Free and Mr. C. E. Blakely visited Fort Monmouth on March 27 and discussed the progress to date on this contract with Mr. A. H. Gottfried.

IV. FACTUAL DATA

A. General

Laboratory measurements were performed on the radio repeater consisting of an AN/GRC-19 and an AN/VRC-14 under simulated operating conditions to verify the previously calculated Mutual Interference Charts. A block diagram of the laboratory test setup used to obtain the data for all the experimental charts is shown in Figure 1. The fixed 20-decibel attenuator, shown in Figure 1, was used to simulate the attenuation in field strength between transmitting and receiving antennas. This value of attenuation was chosen because the maximum estimated signal at the receiver antenna terminals will be 20 decibels below the signal at the transmitter antenna terminals when the antennas are mounted on the jeep.

The mutual interference measurements were made, using the test setup shown in Figure 1, in accordance with the procedures outlined in Sections B, C, and D following.

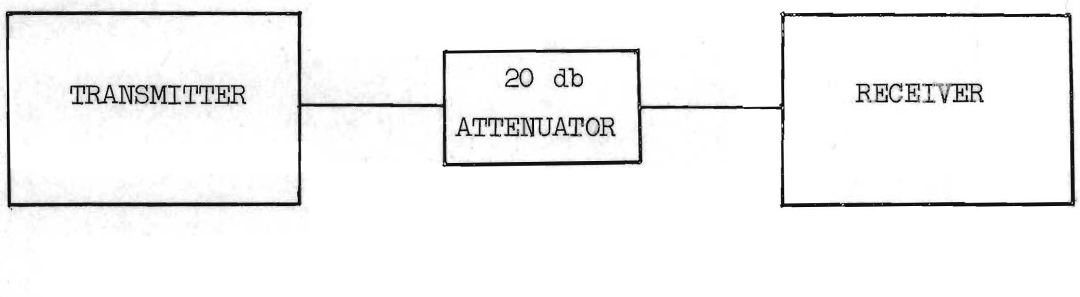

Figure 1. Block Diagram of the Test Setup.

B. Mutual Interference for the T-195/GRC-19—RT-67/GRC Transmitter-Receiver Combination

With the T-195/GRC-19 transmitter operating at a particular frequency the RT-67/GRC receiver was tuned through its frequency range. Receiver frequencies were then recorded where quieting or an audible output from the receiver was detected. This procedure was then repeated for several tuned frequencies of the transmitter which were evenly spaced throughout the T-195/GRC-19 tuning range. The experimental T-195/GRC-19—RT-67/GRC MIC shown as Figure 2 was then constructed from data collected by this procedure. After constructing the chart it was necessary to identify the interference source at each interference frequency. This was done by means of "a priori" information obtained by testing each equipment separately. The identifications are made in Figure 2 in terms of transmitter harmonics and receiver spurious responses.

A comparison of Figure 2 with the theoretical chart (Figure 1, Quarterly Technical Report No. 1) shows that the agreement between the charts is good.

C. Mutual Interference for the RT-67/VRC-14—R-392/URR Transmitter-Receiver Combination

Measurements using the test setup of Figure 1 were made on the RT-67/VRC-14—R-392/URR transmitter-receiver combination. The transmitter test frequencies for this chart (Figure 3) were determined by an examination of the master theoretical MIC. Two points were chosen on each theoretical response line due to the R-392/URR receiver's first and second mixers, one at the low and the other at the high end of the frequency band in which the response fell. The RT-67/VRC-14 transmitter was tuned to each of these points and each response detected in the output of the R-392/URR was recorded.

A somewhat different approach was used to measure the third mixer responses of the R-392/URR receiver (Figure 4). Since these responses repeat

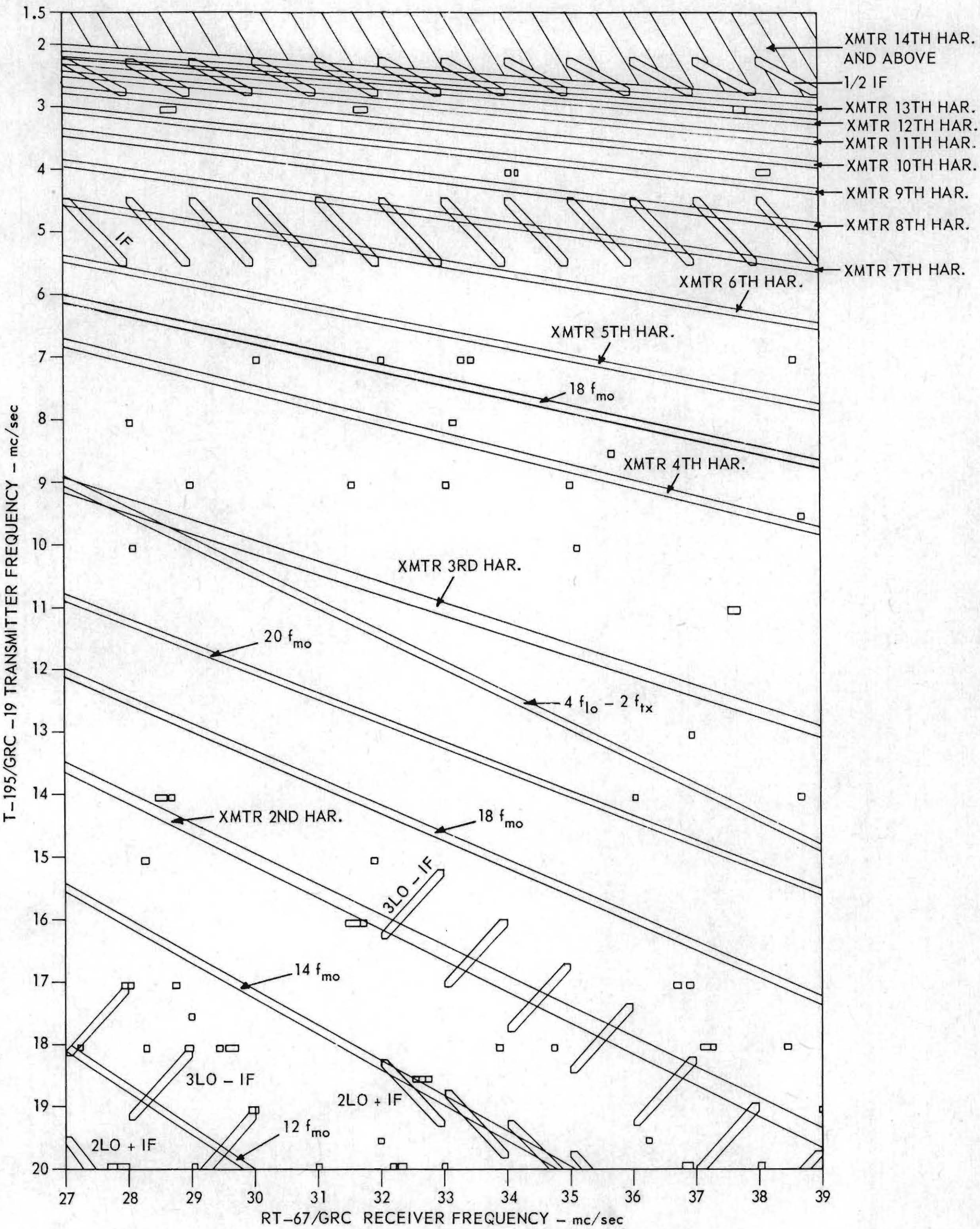

Figure 2. Experimental Mutual Interference Chart for the T-195/GRC-19 -- RT-67/GRC Transmitter Receiver Combination.

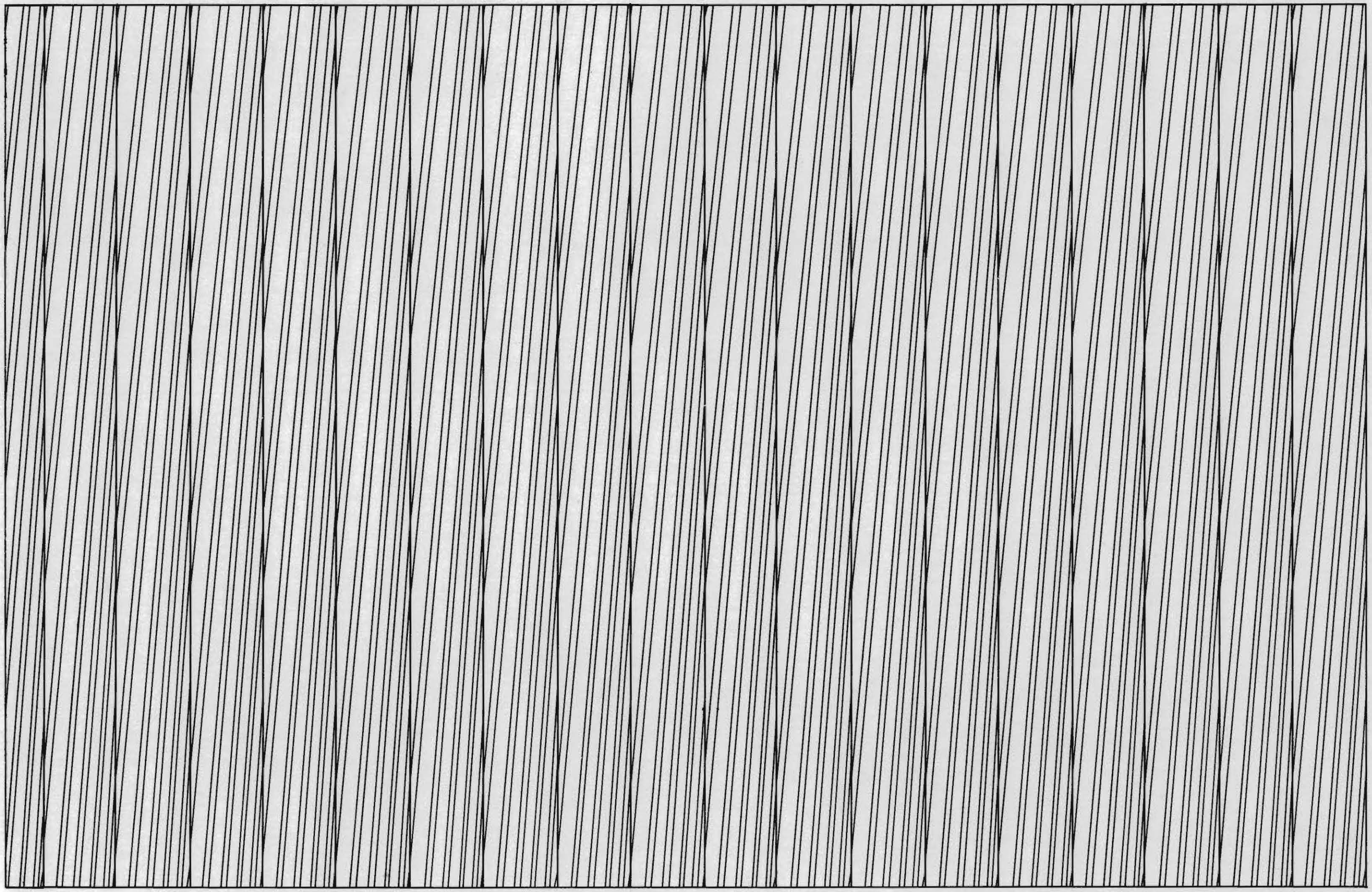

Figure 4. Experimental Mutual Interference Chart for the RT-67/GRC -- R-392/URR Transmitter - Receiver Combination (Third Mixer Responses Only).

on every 1 mc/sec band (Figure 3, Quarterly Technical Report No. 1), four bands were chosen and tested on the R-392/URR receiver; the 5.0- to 6.0-mc/sec band, the 10.0- to 11.0-mc/sec band, the 15.0- to 16.0-mc/sec band, and the 18.0- to 19.0-mc/sec band. For each band chosen, the RT-67/VRC-14 transmitter was tuned to 27.0 mc/sec, 28.0 mc/sec, 30.0 mc/sec, 33.0 mc/sec, 37.0 mc/sec, and 38.9 mc/sec; and for each frequency the R-392/URR receiver was tuned through each band listed above. Responses of sufficient strength to give an output from the R-392/URR receiver were recorded.

Three R-392/URR receivers were chosen for this test. Two of these receivers were of the "double-tuned" r-f input type on the frequency bands 2.0- to 16.0-mc/sec and one was a "single-tuned" r-f input type over the entire frequency range of the receiver. The results show no noticeable difference in the interference susceptibility between the "double-tuned" and "single-tuned" receivers.

Only two changes had to be made on the theoretical RT-67/VRC-14—R-392/URR transmitter-receiver MIC for first and second mixer responses (Figure 2, Quarterly Technical Report No. 1). On the 3.0- to 4.0-mc/sec band of the R-392/URR receiver, the $f_{lo} + f_{if}$ line and the $4f_{lo} - f_{if}$ line did not appear on the measured chart. All other theoretical responses due to the first and second mixers were found. There are no corrections to be made on the second mixer theoretical RT-67/VRC-14—R-392/URR transmitter-receiver MIC (Figure 3, Quarterly Technical Report No. 1).

As in the case of the T-195/GRC-19 transmitter emissions, signals emitted from the RT-67/VRC-14 had been previously identified by measuring the spurious and harmonic outputs, and the spurious responses of the R-392/URR receiver had also been evaluated separately.

D. Receiver-to-Receiver Mutual Interference

The receiver section of the RT-67/GRC uses the same crystal frequencies as the transmitter section; therefore these frequencies and their harmonics are radiated from the receiver antenna terminals, when the receiver is on, with sufficient power to interfere with the R-392/URR receiver. The crystal frequency is a constant for any band of the RT-67/GRC. For example, the crystal frequency used for the 27.0- to 27.9-mc/sec band is 7.51666 mc/sec and retains this value as the RT-67/GRC is tuned from 27.0-to 27.9-mc/sec. Therefore these responses appear as horizontal lines on the experimental receiver-to-receiver MIC shown in Figure 5, and appear as vertical lines on the theoretical chart Figure 2 of Quarterly Technical Report No. 1.

The R-392/URR receiver uses two crystal oscillators (i.e., first and second local oscillators) for heterodyne action over the bands 0.5- to 8.0-mc/sec, whereas only one crystal local oscillator is used from 8.0-to 20.0-mc/sec. Since these oscillator frequencies are radiated from the R-392/URR receiver antenna terminals, these frequencies are sources of possible interference in the RT-67/GRC receiver. These responses appear as vertical lines on the experimental receiver-to-receiver MIC of Figure 5.

The 20-decibel attenuator shown in Figure 1 was inserted between the receiver antenna terminals, and measurements were made on both receivers to detect any responses caused by crystal oscillator frequencies and their harmonics.

All of the calculated frequencies of the RT-67/GRC receiver crystal oscillator were detected in the R-392/URR receiver with the 20-decibel attenuator in the circuit. On the other hand, only four of the total 26 possible responses due to the R-392/URR crystal oscillator frequencies were detected in the RT-67/GRC using the 20-decibel attenuator. All 26 possible

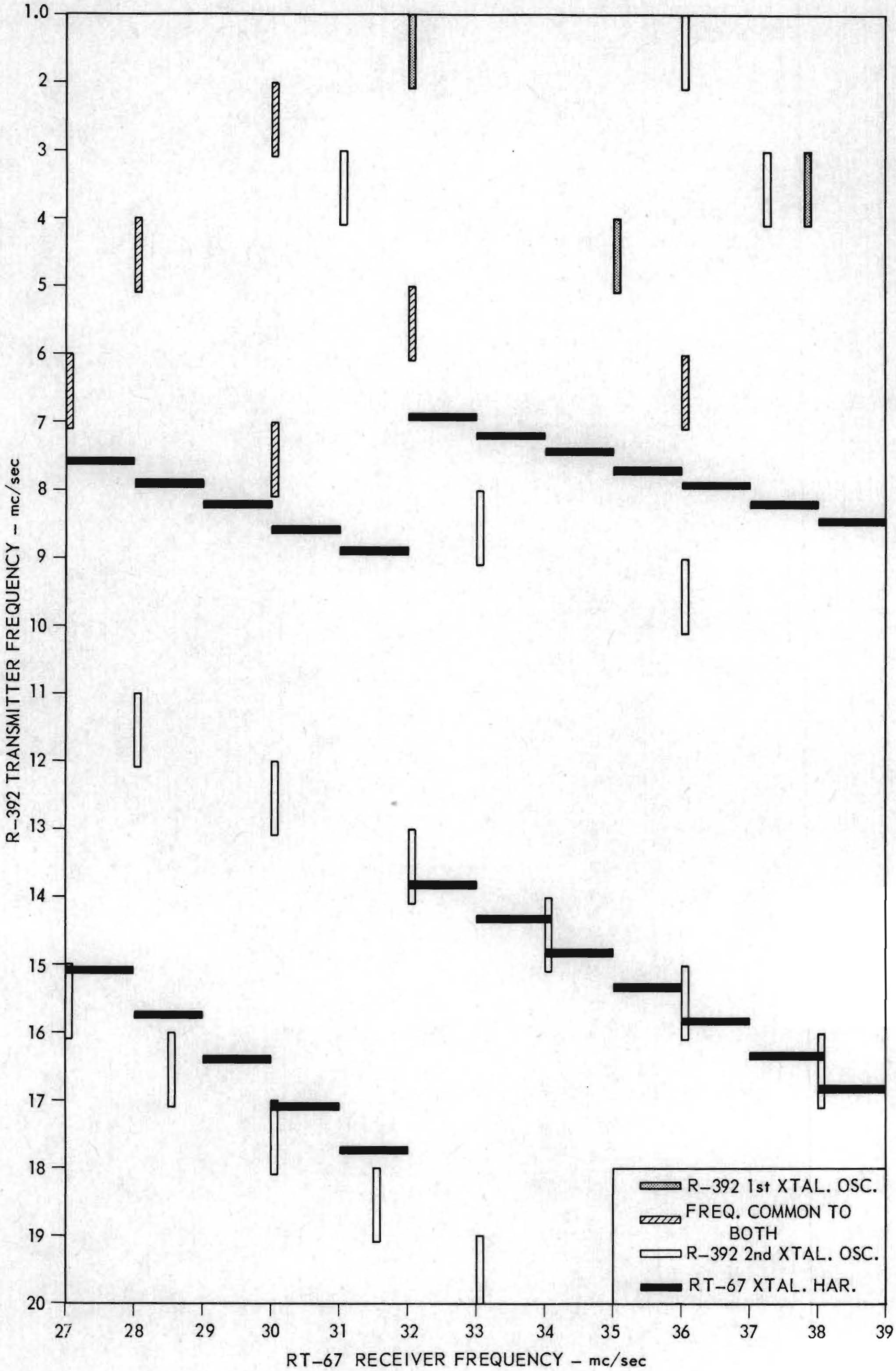

Figure 5. Mutual Interference Chart for the R-392/URR -- RT-67/GRC Receiver - Receiver Combination.

responses were found when the 20-decibel attenuator was removed from the circuit and the output of the R-392/URR receiver was fed directly into the antenna input terminals of the RT-67/GRC receiver. Therefore, if the set-to-set variation in local oscillator radiations is not greater than 20 decibels, these radiations will not be a source of interference.

A measurement was made on the RT-67/GRC receiver to determine the levels of its crystal oscillator emissions. Only the fundamental and second harmonic levels of the crystal oscillator frequencies of the RT-67/GRC are of interest because higher order harmonics fall outside the R-392/URR tuning range. The maximum output occurs on the 31.00- to 31.99-mc/sec band at a level of -107 dbm. The R-392/URR receiver local-oscillator radiations are too weak to measure with ordinary field strength meters but are strong enough to affect sensitive FM receivers.

V. CONCLUSIONS

The interference frequencies encountered in practice, for 20 decibels of decoupling between antennas, agrees very closely with those calculated. If 30 decibels of isolation could be obtained between the transmitting and receiving antennas in field use, most of the interference observed for the RT-67/GRC—R-392/URR transmitter-receiver combination would disappear.

Receiver-to-receiver interference will exist in some installations where the local oscillator radiations are high. In general, these frequencies should probably be avoided.

VI. PROGRAM FOR NEXT INTERVAL

Field tests will be initiated early in the next report period using typical antenna installations. The results of these tests will be used to further enhance the accuracy of the experimental MIC's.

The charts will be spot checked only, since just a few frequencies are available for field use.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

C. E. Blakely	Project Director Research Engineer	77 hours
W. R. Free	Assistant Research Engineer	51 hours
H. H. Jenkins	Assistant Research Engineer	51 hours
W. M. Peacock	Student Assistant	154 hours

Respectively submitted:

Charles E. Blakely

C. E. Blakely,
Project Director

Approved:

A. L. Bennett

A. L. Bennett, Chief
Physical Sciences Division

VIII. ERRATA

Table I of Quarterly Technical Report No. 1 contains the following errors. Line 1 Column 3 should be 15.0333, line 1 column 4 should be 22.55, line 9 column 2 should be 7.6375, line 9 column 3 should be 15.2750, line 9 column 4 should be 22.9125, line 10 column 3 should be 15.7750 and line 12 column 2 should be 8.3875.

FINAL TECHNICAL REPORT

PROJECT NO. A-418

MUTUAL INTERFERENCE CHARTS FOR A RADIO REPEATER SET

By

C. E. BLAKELY, R. N. BAILEY,
H. H. JENKINS, W. M. ROGERS
and T. T. SPENGLER

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CONTRACT NO. DA-36-039-sc-78243
DEPARTMENT OF THE ARMY PROJECT: 3-24-01-291

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1 NOVEMBER 1958 TO 30 OCTOBER 1959

PLACED BY THE U. S. ARMY
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Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

AD ____________________ Accession No. __________
Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia

Final Technical Report, 1 November 1958 to 30 October 1959, 40 pp - 3 illus
(Contract DA-36-039-sc-78243) DA Project 3-24-01-291, Unclassified Report

A summary of the work accomplished during the project period and the method of construction of mutual interference charts are presented. The final charts as modified by laboratory and field tests are presented. Instructions for using these charts to obtain interference-free frequencies are also included.

UNCLASSIFIED
Mutual Interference
Charts for a Radio
Repeater Set

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1 NOVEMBER 1958 TO 30 OCTOBER 1959

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This report contains 40 pages.

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The purpose of this investigation is to determine compatible operating frequencies for the AN/GRC-19 and AN/VRC-14 when operated as a radio repeater.

A theoretical Mutual Interference Chart (MIC), constructed by means of linear equations, is to be used as the basis for this study. These charts will be modified by laboratory and field measurements to further enhance their accuracy. They will then become part of the final report to be used in selecting operating frequencies.

II. ABSTRACT

A summary of the work accomplished during the project period and the method of construction of mutual interference charts are presented. The final charts as modified by laboratory and field tests are presented. Instructions for using these charts to obtain interference-free frequencies are also included.

III. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

Mr. W. B. Wrigley visited Fort Monmouth on December 8, 1958 to discuss technical specifications for the mutual interference charts and the availability of test frequencies for field uses.

Mr. S. Weitz, Mr. A. H. Gottfried, Mr. J. F. Chappell, and Mr. H. F. Hecker of USASRDL visited Georgia Tech on February 4 and 5, 1959. Project results and progress to date were discussed.

Mr. C. E. Blakely and Mr. W. R. Free visited Fort Monmouth on March 27, 1959 and discussed the project progress with Mr. A. H. Gottfried.

Mr. C. E. Blakely and Mr. W. M. Rogers visited Fort Monmouth on July 28, 1959. The progress to date on this contract was discussed with Mr. A. H. Gottfried and Mr. S. Weitz.

Mr. C. E. Blakely, Mr. R. N. Bailey, Dr. I. E. Perlin and Mr. W. M. Rogers attended the Fifth Conference on Radio Interference Reduction and Electronic Compatability held on October 6, 7 and 8, 1959 at the Museum of Science and Industry, Chicago, Illinois. Papers entitled "The Construction of Mutual Interference Charts and Some Statistical Properties of the Entries" and "The Prediction of Intermodulation Characteristics of Communication Equipment" were presented at the conference by Mr. Blakely and Mr. Rogers, respectively.

IV. FACTUAL DATA

A. General

The determination of compatible operating frequencies for any transmitting and receiving equipment requires the determination of mutually interfering frequencies and the arrangement of this information in a form that is readily usable. The mutually interfering frequencies may be determined by utilizing mutual interference charts (MIC's) or matrices constructed by use of experimentally-proven linear frequency equations.[1] In general, the chart or matrix will contain interfering frequencies which are not actually present in the normal operating setup. It becomes necessary, then, to determine by experimental sampling, those frequencies which will create mutual interference under actual operating conditions. This means that for maximum accuracy a large number of field test frequencies must be used, which in most cases are not available. An alternate method, which yields good results, is to use a few field test frequencies which are located within bands where the maximum amount of interference (maximum numbers of interfering frequencies) exist, as established by laboratory measurements. This alternate method allows trends to be established from which the mutual interference chart can be constructed. If the variation from set to set is considered, it can be seen that the chart accuracy, when this method is used, is probably sufficient, especially if a large number of different serial numbered equipments are to be used. The final data for the charts contained in this report were obtained according to the three steps outlined in the following sections B, C and D.

B. Theoretical Chart

The radio repeater set for which these MIC's were constructed consists of

[1] Blakely, C. E., et al., "Mutual Interference Charts for a Radio Repeater Set," Quarterly Technical Report Nos. 1, 2 and 3, Contract No. DA-36-039-sc-78243, U. S. Army Signal Engineering Laboratories, Fort Monmouth, N. J.

two transmitters and two receivers. Since only one transmitter and one receiver are used simultaneously, the initial approach was to consider each set separately; that is, each transmitter-receiver combination was considerated separately. Each equipment involved in the "set" was analyzed for methods of signal generation and/or signal conversion. The information obtained from this analysis was used for the formulation of linear frequency equations describing the emission frequencies of the transmitters and receivers and the spurious response frequencies of the receivers. These equations were used to calculate interfering frequencies for the construction of two theoretical MIC's, one for each "set". The MIC's thus constructed contained all the theoretical interfering frequencies that were calculated, with suitable limits on the frequency equations. (A complete discussion of the linear frequency equations and theoretical charts may be found in Quarterly Technical Report #1.)

C. Laboratory Measurements

Laboratory measurements were performed on the radio repeater set under simulated normal operating conditions. The transmitter and receiver were operated with resistive dummy loads connected to the antenna terminals and the transmitter output connected to the receiver antenna terminals through a 20-decibel attenuator to simulate estimated coupling between the transmitting and receiving antennas. These measurements were made by tuning the receiver through its entire range for each transmitter frequency and noting all responses. The responses thus determined were identified by comparing their frequencies with a set of theoretical response frequencies that had been calculated previously by the use of linear equations.

During these tests, responses which had not been previously identified by linear equations were discovered. Also, some responses which had been identified by linear equations were not present. The data thus obtained from laboratory experiments were used to modify the theoretical mutual interference charts. In the modification of the charts the interference bands were located from the measured data points and then extended by the use of the linear frequency equations.

D. Field Measurements

Interference measurements were performed under typical field conditions for the RT-67/GRC--R-392/URR transmitter-receiver combination, the T-195/GRC--RT-67/VRC-14 transmitter-receiver combination, and the RT-67/VRC-14--R-392/URR receiver-receiver combination.

The field interference measurements were made using seven different AM and seven different FM transmitter frequencies, and with the equipment and antennas in their normal operating configuration. Some changes were made in the MIC's on the basis of these tests, but, in general, the interfering frequencies found in these tests showed good correlation with those found in the laboratory tests. However, a great deal of additional interference due to intermodulation was encountered in the field tests. This intermodulation could not have been predicted in advance.[2] Also, some weak interference was found which could not be identified either as intermodulation or by the linear frequency equations. In any case, these latter responses were not strong enough to cause appreciable interference.

Tests were made to determine if an interfering signal was sufficient to hold the squelch open (and the transmitter keyed) after the desired signal was removed. It was found that most of the interference will hold the receivers unsquelched, and in addition, some interference is sufficient to unsquelch the

[2] Intermodulation could not be predicted and shown on the MIC because it was caused, in this case, by mixing within the receiver of the local transmitter signal with other signals which originated outside the system. A more complete discussion of the intermodulation effect may be found in Quarterly Technical Report #3.

receivers with no desired signal present. Other than this, the effect of a large percentage of the interference can be disregarded in the presence of a relatively large desired signal.

Another effect which was noticed during the field tests was the degradation of receiver sensitivity due to power supply noise. A complete discussion of this effect is contained in Quarterly Technical Report #3.

Antenna coupling measurements were made using a signal generator to drive the transmitting antenna and a field strength meter to monitor the voltage at the receiving antenna terminals. The antenna coupling at each frequency was defined as the difference between the field strength meter reading in decibels and the signal generator reading in decibels. The results of these measurements are shown in Figure 1. This curve differs from the one published in Quarterly Technical Report #3 in that the T-195 transmitter was used as the signal source for the data shown in that curve, and the coupling was defined as the difference between the field strength meter readings and the transmitter spurious and harmonic emissions into a 50-ohm resistive load.

The purpose in obtaining these curves was to determine the effect of antenna impedances on the spurious and harmonic output as measured into a resistive load and to verify the estimate of antenna coupling. The results of these rudimentary measurements show that the estimate of 20-decibels coupling between receiving and transmitting antennas was sufficiently pessimistic.

E. Construction and Use of Mutual Interference Charts

1. Construction - General

a. Layout Mutual interference charts are constructed on rectangular coordinate paper with each channel represented by the space between two grid lines. The most common MIC's are those which compare two equipments, usually

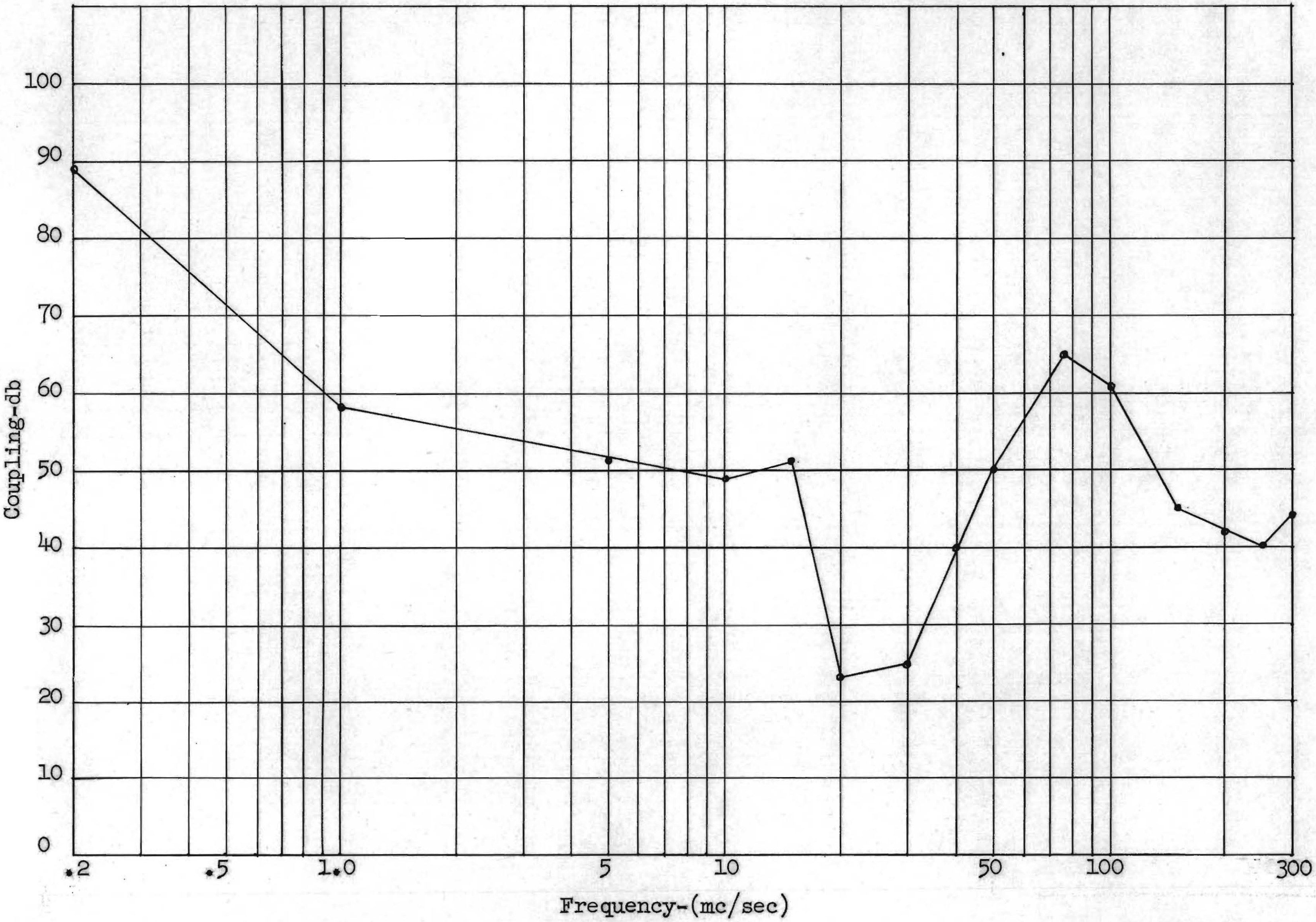


Figure 1. Whip-to-Dipole Antenna Coupling for AN/VRC-14--AN/GRC-19 Radio Relay Set as Measured by the Signal Generator Method.

a transmitter and a receiver. One axis represents the transmitter tuned frequency, and the other, the receiver tuned frequency. The lengths of the axis represent the tuning ranges of the equipments examined.

The principal divisions (those that can be read from the chart directly, without graphical interpolation) are placed so that they fall between the grid lines as noted above. This is done so that the center of a box or square formed by two pairs of adjacent grid lines will represent a principal frequency pair. Interference is then represented by a black square, and no interference by a white square.

b. Scales It is most convenient to consider the frequency range of an equipment as being divided into a number of discrete channels. (This is actually the case for many systems.) The scale for each axis is selected such that the smallest division equals one channel in the frequency range of the equipment represented by that axis. Maximum feasible resolution on the MIC is achieved by using this method.

c. Interference Plotting For most cases, interference attributed to a specific source will appear as a band of non-permissible frequency combinations across the MIC (shown in black). Usually guard bands will be set up according to the seriousness of the interference. If the guard band is equal to the channel spacing, a single straight guide line is drawn over the band of interfering frequency pairs. Each box which is cut by this line is considered to be an interfering frequency pair, and is so designated on the chart. If the line passes diagonally between two boxes, neither box is cut, and the frequency pairs represented by the boxes are not considered to be interfering. (This is because the distance from the line to the center of each box is greater than one-half the channel spacing.)

If the guard band is greater than one channel-width, the line between calculated end points is drawn as before. Next, parallel limit lines are drawn on either side of the guide line to represent the interference or guard band. The selection of interfering frequencies is as above, but the limit lines are used instead of the guide line.

2. Construction of the RT-67 Transmitter--R-392-Receiver MIC

a. General There are two types of interference shown on this chart. (See Appendix.) These are listed below and for convenience as well as clarity they will be discussed separately.

(1) Spurious responses of the R-392 that may be caused by the fundamental emission of the RT-67 transmitter

(2) Co-channel interference that may be caused by oscillators contained in the RT-67 which operate in the frequency range of the R-392

b. Spurious Responses Three sets of receiver spurious responses appear on this chart due to the first, second, and third mixer. The first and second mixer responses will be discussed together.

(1) First and Second Mixer Responses First mixer spurious responses will appear on the chart only between 1.5 and 8 mc/sec, while the second mixer responses may appear anywhere in the range from 1.5 to 20 mc/sec. These responses are shown as bands each of which extends over a range of 1 mc/sec along the receiver axis and has a slope of either +1 or -1. Some of the first and second mixer responses are coincident.

Notice that the top and bottom of each receiver tuning band is an integral frequency (2.0 - 3.0 mc/sec, 3.0 - 4.0 mc/sec, etc.). These frequencies may be tuned on two adjacent receiver bands. Hence, it is possible to have spurious response interference present at the top of one receiver band and not at the bottom of the next. This effect could not be distinguished on the chart unless each band was shown separately, which was not feasible.

(2) Third Mixer Responses Third mixer responses are shown as a number of bands of interference each of which extends over 1 mc/sec along the receiver axis. These bands have varying negative slopes, which increase (approach the vertical) as the order of p increases in the equation

$$27.0 \leq p\, f_{lo_3} \pm f_{if_3} \leq 38.9\ , \tag{1}$$

where p = integers, 8, 9, 10, 11, 12, 13, 14, 15, or 16; f_{lo_3} = third local oscillator frequency; and, f_{if_3} = third intermediate frequency. Unlike the first and second mixer responses, the third mixer responses are repeated for each receiver band.

c. Co-Channel Interference Co-channel interference in the R-392 is caused by a crystal oscillator and a variable frequency oscillator located in the RT-67.

(1) Co-channel Interference Due to the RT-67 Crystal Oscillator The crystal oscillator operates at a single frequency over any given one megacycle band in the RT-67 tuning range; consequently, this interference is shown as vertical lines which extend over 1 mc/sec intervals along the transmitter axis. Harmonics of these crystal oscillator frequencies also appear, and are shown in the same way.

(2) Co-channel Interference Due to the Variable Frequency Oscillator The variable frequency oscillator (called the transmitter oscillator) has a fundamental frequency range of 4.45 to 5.45 mc/sec. This interference appears on the MIC as bands which extend from 4.45 to 5.45 mc/sec on the receiver axis, and have a slope of 1. The bands are repeated at one megacycle intervals along the transmitter axis. Also shown is the interference caused by the third harmonic of the transmitter oscillator frequency. This appears as bands which extend from 13.35 to 16.35 mc/sec on the receiver axis, and have a slope of 1/3. These bands are also repeated as discussed above at one megacycle intervals along the transmitter axis.

3. Construction of the T-195 Transmitter--RT-67 Receiver MIC

a. General Interference shown on this chart (see Appendix) is caused either by harmonics of the transmitter fundamental, or harmonics of the master oscillator falling at the receiver tuned frequency, or by the transmitter fundamental or second harmonic frequency feeding directly through to the receiver i-f, or by crystal oscillator emissions from the R-392 receiver.

b. T-195 Harmonic Emissions The co-channel interference caused by harmonic signals emanated from the T-195 transmitter is shown on the chart as a number of bands with varying negative slopes which increase (approach vertical) as the harmonic order increases.

The interference caused by the feedthrough of the T-195 fundamental frequency at the receiver intermediate frequency is shown as bands which extend from 4.45 to 5.45 mc/sec along the transmitter axis, and have a slope of 1. These bands repeat at one megacycle intervals along the receiver axis. Interference caused by the T-195 second harmonic frequency feedthrough at the receiver i-f is shown on the MIC as bands which extend from 2.225 to 2.725 mc/sec along the transmitter axis, and have a slope of 2. These bands repeat as was discussed above.

c. Interference Emanated by the R-392 Although this type of interference is classed strictly as receiver-to-receiver interference, it is convenient to show this on the T-195-to-RT-67 chart as receiver co-channel interference. This interference, caused by harmonics of the crystal-controlled local oscillators contained in the R-392 receiver, appears on the MIC as horizontal bands extending 1 mc/sec along the transmitter axis. Notice that these bands are cross-hatched instead of solid black to indicate that these frequencies may be used if the R-392 is tuned to some other frequency.

4. Use of Mutual Interference Charts

When a list of proposed operating frequencies are available, permissible operating frequencies may be selected in a relatively straightforward manner by using the MIC's. The following step-by-step procedure is for clarification and illustration of the method used in selecting permissible frequencies.

a. Select a frequency from the list for the T-195 transmitter.

b. Find this frequency on the T-195/GRC-19--RT-67/GRC transmitter-receiver combination.

c. Move vertically up the chart along the selected frequency line and check each RT-67 receiver frequency on the list until a permissible frequency is found. A black square at the intersection of the transmitter and receiver frequencies indicates a non-permissible frequency; whereas a white square indicates a permissible frequency.

If no permissible frequency is found return to step a and select another T-195/GRC-19 transmitter frequency.

d. Use the permissible RT-67 receiver frequency found in step c as the RT-67 transmitter frequency.

e. Find this frequency on the RT-67/GRC--R-392/URR transmitter-receiver MIC.

f. Move horizontally across the chart along this line and check each R-392/URR receiver frequency on the list until a permissible frequency is found. If no permissible frequency is found, return to step c and select another RT-67/GRC frequency, and repeat steps d, e and f.

g. If a permissible frequency is still not found, return to step a and select another T-195/GRC-19 transmitter frequency, and then repeat steps b through f.

h. After a permissible R-392/URR receiver frequency is found, return to the T-195/GRC-19--RT-67/GRC transmitter-receiver chart.

i. Using the permissible R-392/URR receiver frequency enter the chart on the T-195/GRC-19 axis and follow this line up to the intersection of this frequency with the permissible RT-67/GRC frequency previously selected. If a cross-hatch is present the R-392/URR receiver frequency is not permissible. The absence of a cross-hatch indicates a permissible frequency, and a complete set of permissible frequencies have been found.

j. If the frequency used in step i is not permissible, return to step c, select another RT-67/GRC frequency and repeat the procedure until a complete set of permissible frequencies are found.

k. If interference is experienced after choosing a frequency by the above procedure, it may be due to intermodulation, crossmodulation or co-channel interference caused by external signals. Since these types of interference are a function of the environment in which the equipment is operated, they cannot be shown on the MIC. The following procedure should be used if one of these types of interference is suspected.

(1) Unkey the transmitter that is in use and observe if the interfering signal disappears. If the interference disappears it may be due to intermodulation; therefore, a new transmitter or receiver frequency must be selected.

(Note: In general, R-392/URR receiver tuned frequencies should be no closer than $\pm 1/2$ mc/sec to one-half the RT-67 transmitter frequency, in order to reduce the likelihood of intermodulation interference.)

(2) If the interference is present only when the desired signal is present, it may be due to crossmodulation; therefore, a new receiver tuned frequency must be chosen.

(3) If the interference is present with or without the desired signal and with or without the transmitter keyed, it is due to a co-channel signal; therefore, a new receiver frequency must be selected.

V. SUMMARY AND CONCLUSIONS

The use of laboratory and field measurements is a satisfactory means of verifying and modifying theoretical mutual interference charts. In the opinion of the authors, these experimental data are sufficient for the production of accurate practical charts.

Of course, it may be expected that some of the interfering frequency pairs shown on a mutual interference chart may not, under certain conditions, actually interfere. Such apparent inconsistencies are due to set-to-set variations in the equipment and differences in site arrangement. Also to be expected is the occurrence of some interference not shown on the chart. Intermodulation is a typical effect which cannot be shown on a mutual interference chart since the frequency and severity of occurrences of this type of interference are greatly influenced by site location, antenna orientation, and general r-f environment.

The accuracy and resolution of a mutual interference chart constructed by the methods explained in Sections B, C and D is determined by chart size, accuracy of graphical construction, width of channels, and the determination of guard band limits. Since the frequency axes on a mutual interference chart are divided into discrete channels, and each pair of channels is designated either as being an interfering pair or a non-interfering pair, some slight ambiguity is conceivably introduced. Such ambiguity might result if, say, the chart were drawn for AM channel frequencies at even multiples of 5 kc/sec (1.500, 1.510, 1.520 mc/sec, etc.), and the actual transmitter frequencies were odd multiples of 5 kc/sec (1.505, 1.515 mc/sec, etc.). However, this is of minor consequence.

VI. RECOMMENDATIONS

The replacement of the present squelch-keyed system with some type of selective calling system would greatly reduce interference problems. Although much of the interference that is encountered is quite weak, almost all of it is sufficient to keep a receiver unsquelched and the transmitter keyed after reception of the desired signal is over. Use of a selective calling system (for example, a tone-keyed system) would eliminate this effect and allow the use of more frequencies.

Reduction of power supply noise generation would also do much for the overall improvement of the relay system. This noise, which is present at high levels in the power lines, degrades receiver sensitivity.

The actual construction and preparation of mutual interference charts by manual means is tedious and time-consuming; therefore, an automated procedure is desirable. The production of lists of permissible frequency combinations, which is probably more desirable than the direct production of charts, lends itself to the use of automatic data processing methods. A study of such techniques would probably be rewarding.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Name	Title	No. of Hours
Charles E. Blakely	Project Director Research Engineer	641
Robert N. Bailey	Assistant Research Engineer	569
William R. Free	Assistant Research Engineer	76
Herndon H. Jenkins	Assistant Research Engineer	584
Walker M. Peacock	Student Assistant	310
Walter L. Reagh	Research Assistant	161
Walter M. Rogers, Jr.	Research Assistant	473
Thomas T. Spengler	Student Assistant	360

The background and qualifications of these men are presented in the following paragraphs.

This project is under the direction of Mr. Blakely. He holds the degree of M.S. in E.E. from the University of Tennessee and is currently pursuing studies toward a Ph.D. in that field from the Georgia Institute of Technology. He has previously been associated with the Engineering Experiment Station, University of Tennessee, for 3 years; Edenfield Electric Corporation, Oak Ridge, Tennessee; Carbon Carbide Chemical Corporation, Oak Ridge, Tennessee; Radio Station WUOT, Knoxville, Tennessee; and has been associated with various research projects at Georgia Tech for over two years.

Mr. Bailey holds a B. of E.E. Degree from the Georgia Institute of Technology and is currently pursuing graduate work toward a M.S. Degree in the same field. His previous experience includes four years as radio technician in the USAF; two years maintaining communications equipment for Bailey's Radio Service; and four years as instrument engineer for the E. I. duPont deNemours & Co., Savannah River Plant.

Mr. Free holds a M. S. Degree in Electrical Engineering from the Georgia Institute of Technology. His previous professional experience includes three years as Development Engineer for Sperry Gyroscope Company and one year in crystal oscillator development on another project at Georgia Tech. He served three years as an Electronic Technician in the U. S. Coast Guard.

Mr. Jenkins holds the degree of B.S. in E.E. from the Georgia Institute of Technology. He attended graduate school at Johns Hopkins University and is currently working on an M.S. at the Georgia Institute of Technology. He has previously been associated with the Johns Hopkins University Applied Physics Laboratory.

Mr. Peacock is an undergraduate at the Georgia Institute of Technology. He served 3 years as an Electronics Technician in the U. S. Navy. He has been employed as a technician on various station projects since 1956.

Mr. Reagh has been associated with various projects at the Engineering Experiment Station since 1951. His previous experience includes 11 years as a self-employed radio technician in Tupelo, Mississippi; 7 years as Electronic Technician, Tennessee Eastman Corporation, Oak Ridge, Tennessee; and 3 years as instructor of radio at Georgia Institute of Technology Evening School.

Mr. Rogers holds a B.S. Degree in E.E. from Georgia Institute of Technology and is currently pursuing graduate work toward a M.S. in the same field. His previous experience includes one year in missile guidance system design for Bendix Radio and two years as a Ground Radar and Communications Officer in the U. S. Air Force.

Mr. Spengler is an undergraduate student working toward a B.S. Degree in I.M. at Georgia Tech.

Respectfully submitted:

Charles E. Blakely

Charles E. Blakely,
Project Director

Approved:

J E Boyd

J. E. Boyd, Director
Engineering Experiment Station

VIII. APPENDIX

Figures 2 and 3 are the Mutual Interference Charts for the T-195 transmitter--RT-67 receiver combination and the RT-67 transmitter--R-392 receiver combination, respectively. A procedure for using these charts to select compatible operating frequencies is described in part E of Section IV.

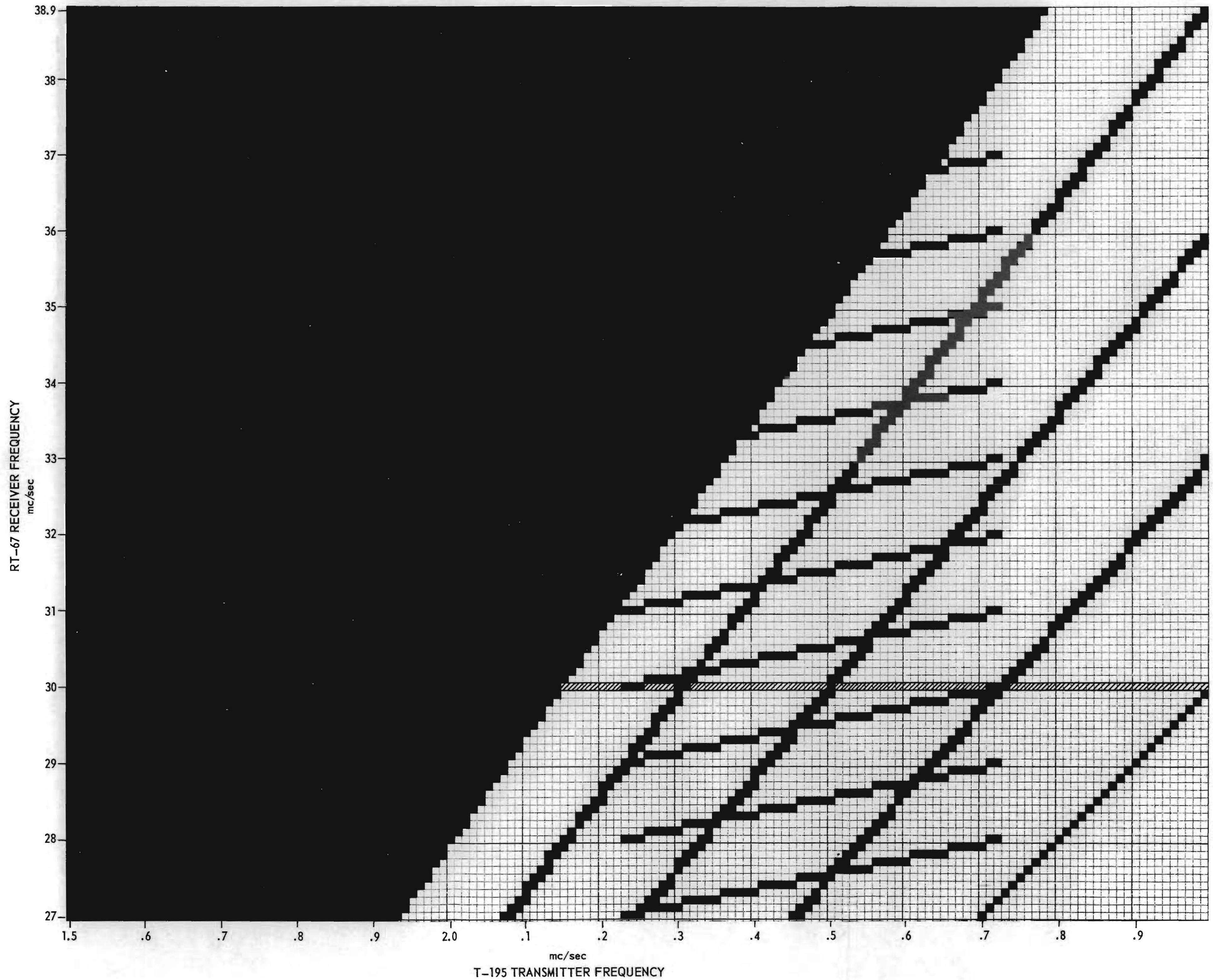
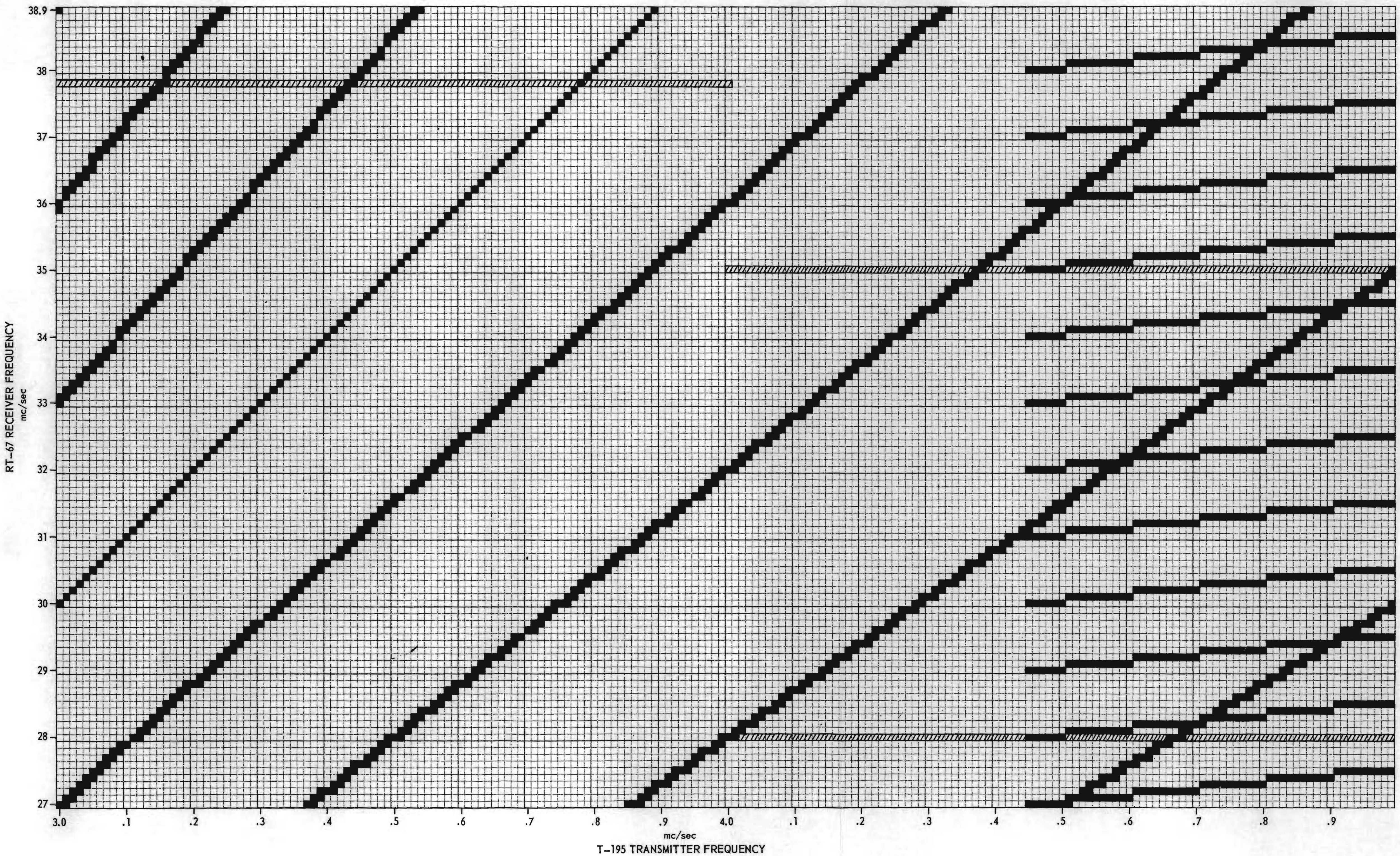


Figure 2. Mutual Interference Chart for the T-195 Transmitter -- RT-67 Receiver Combination.



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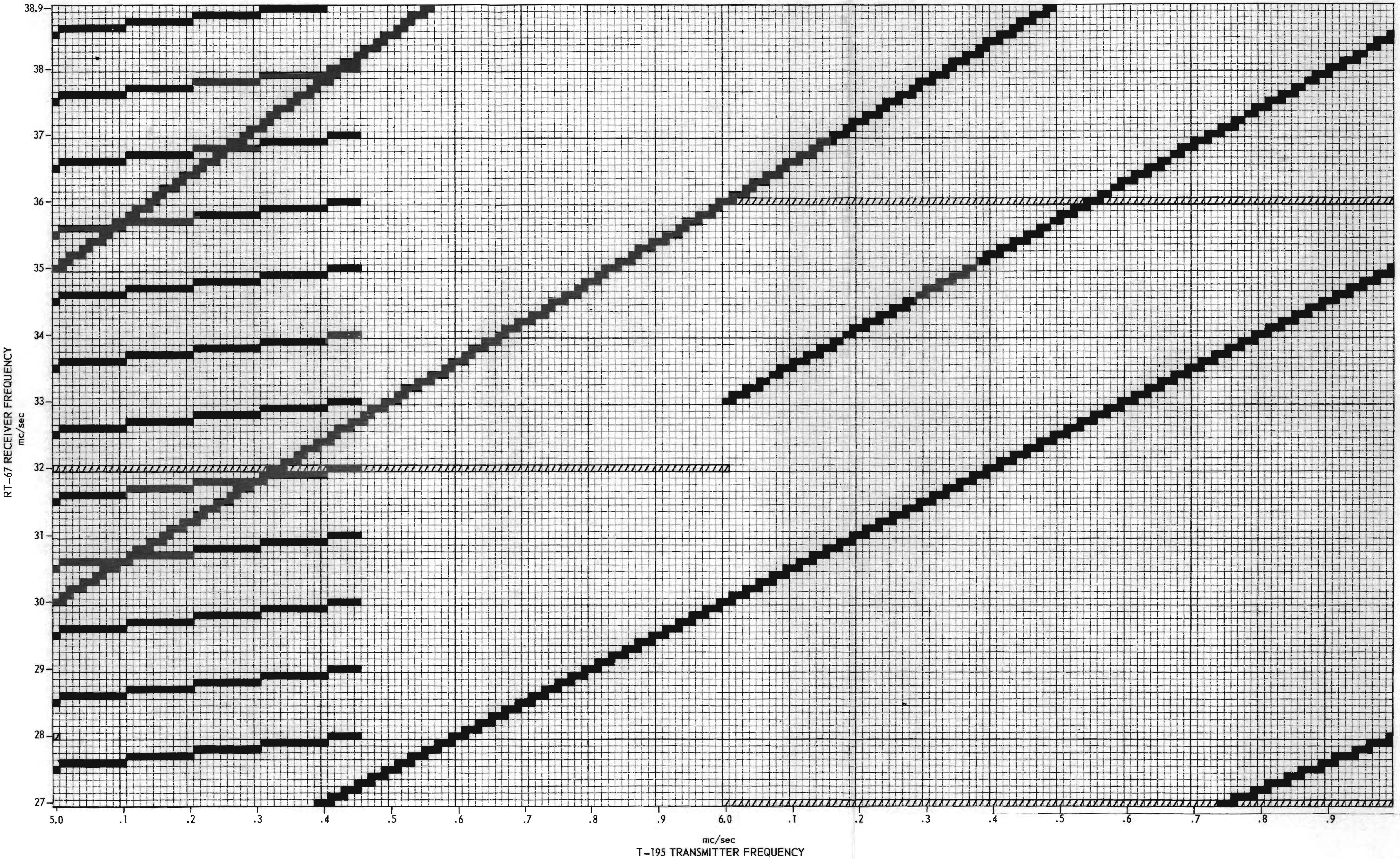

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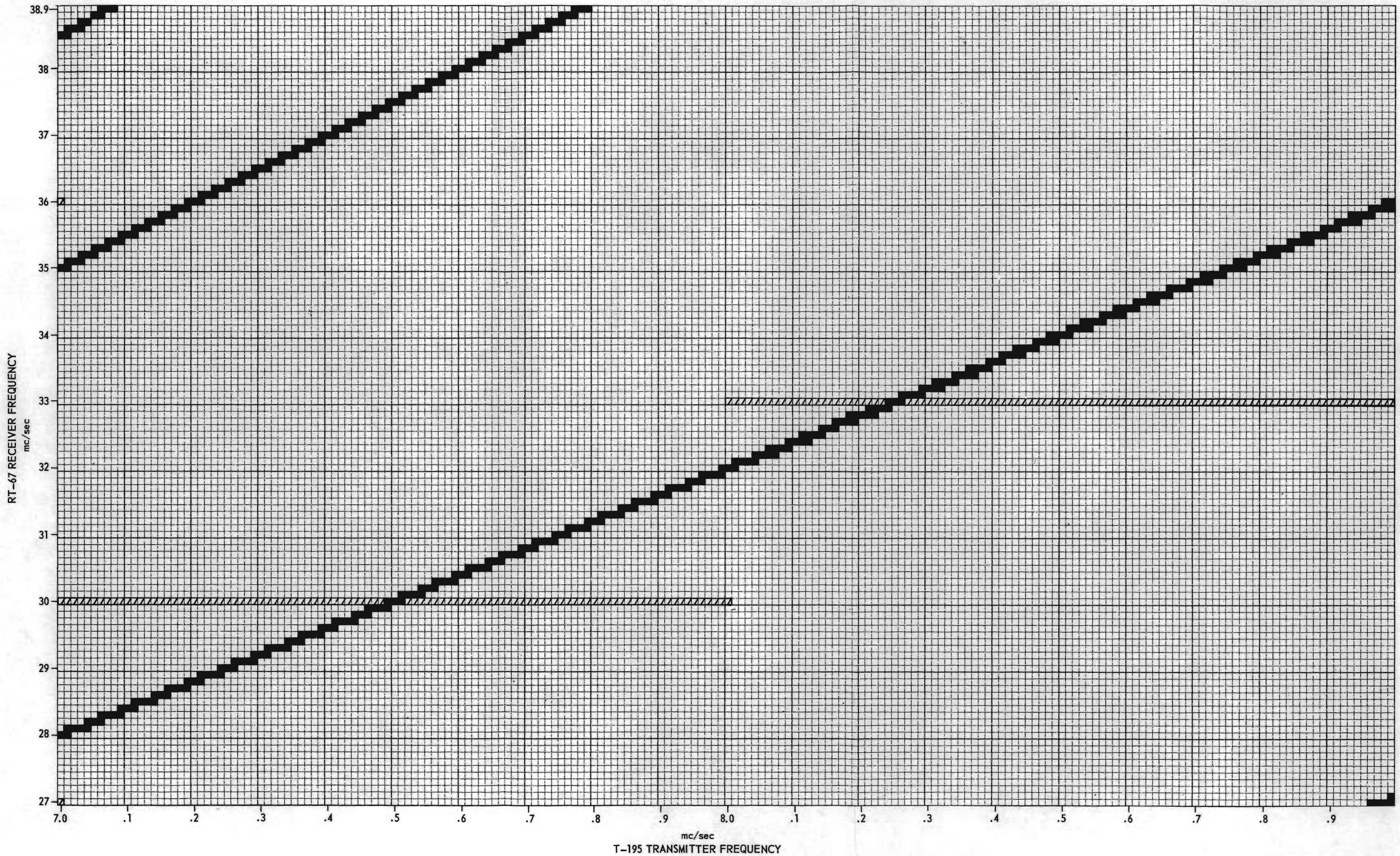

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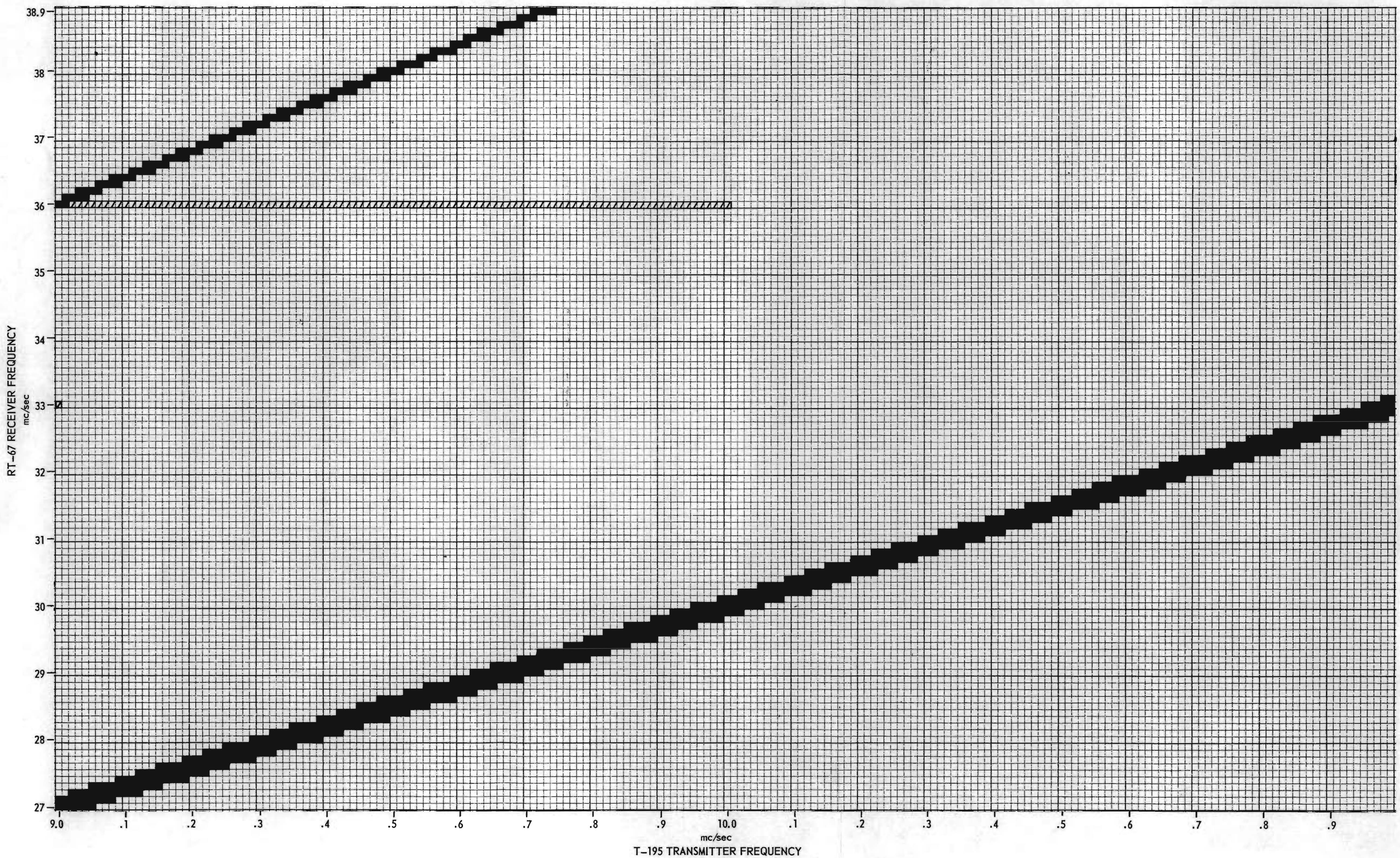

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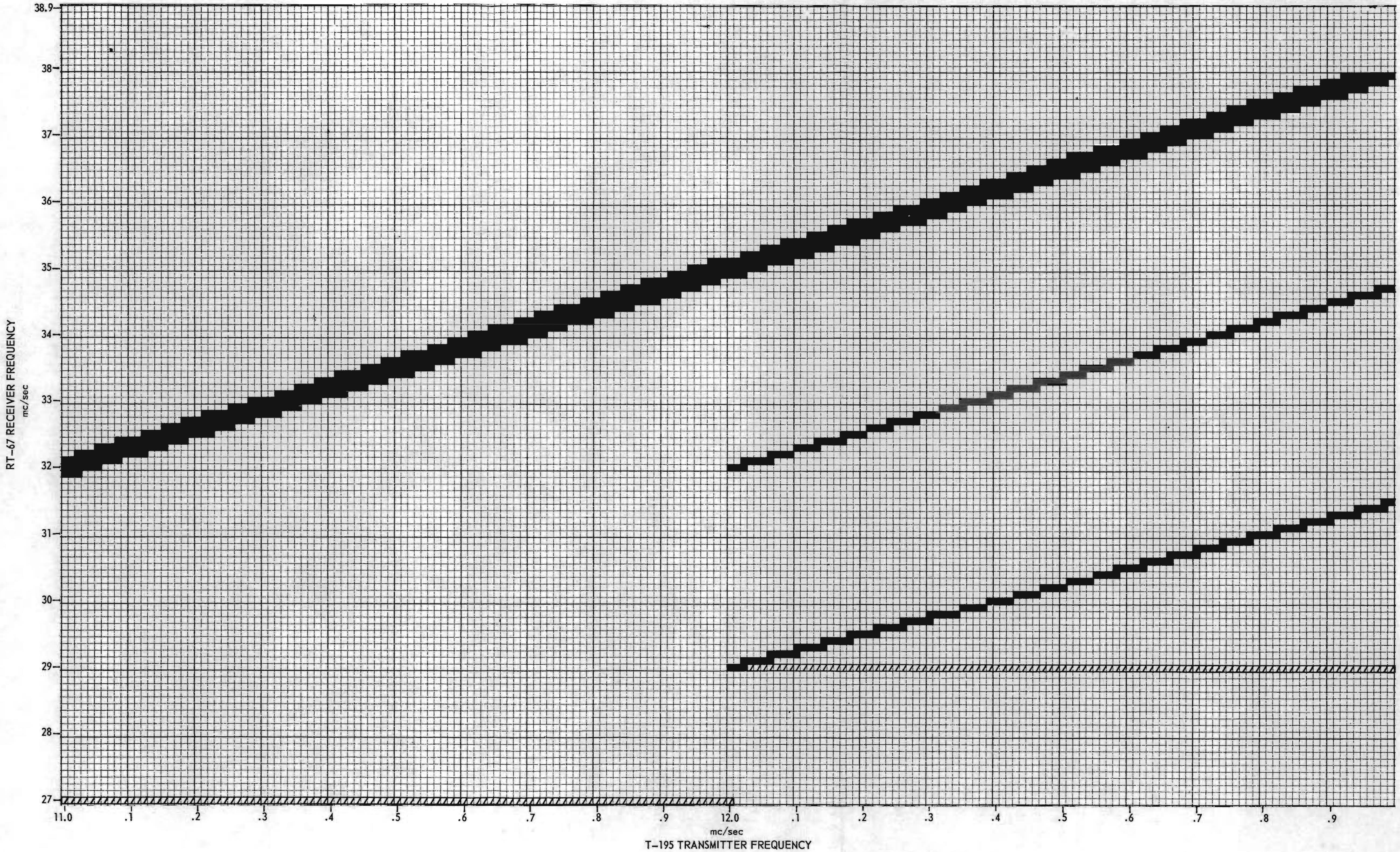

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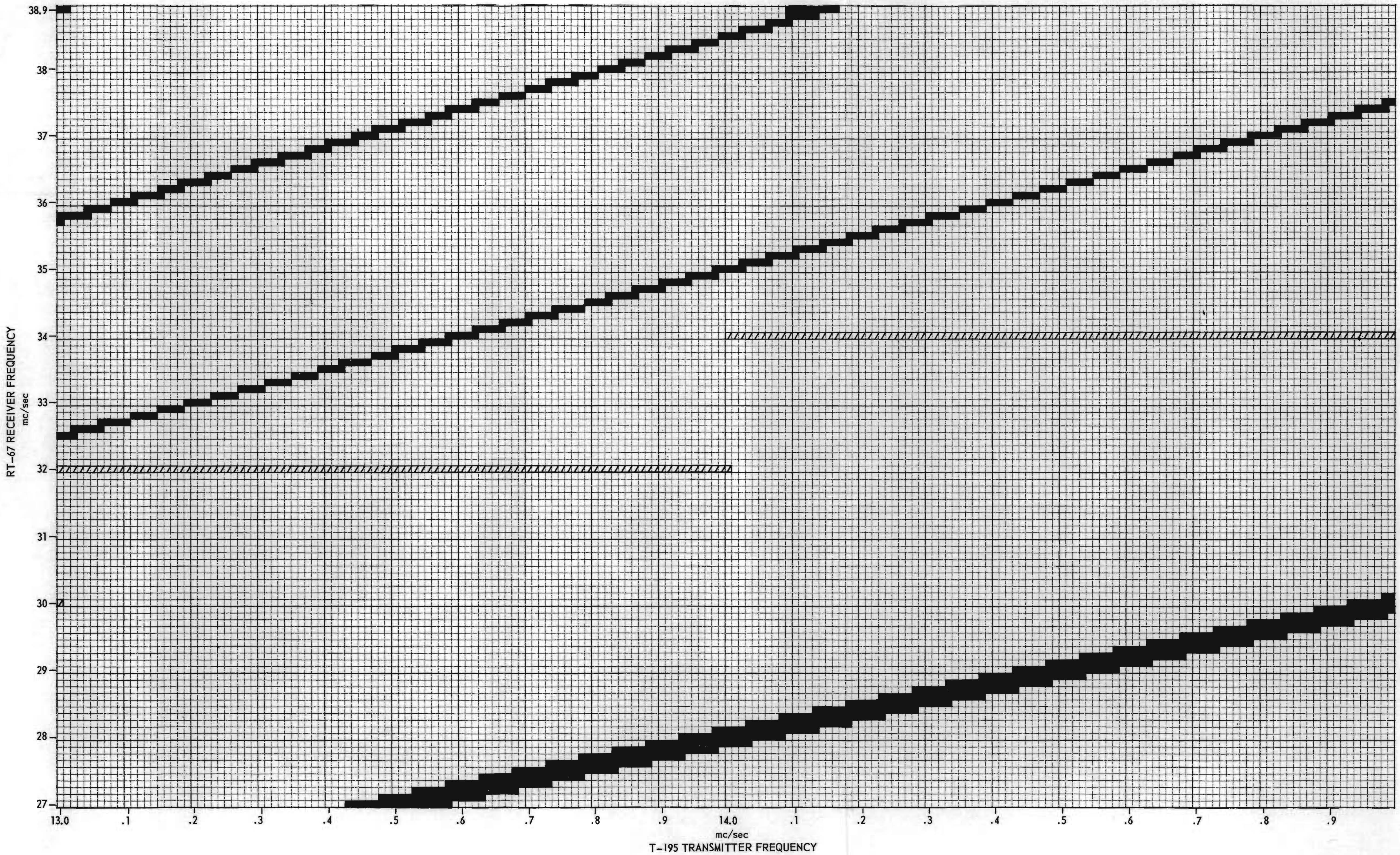

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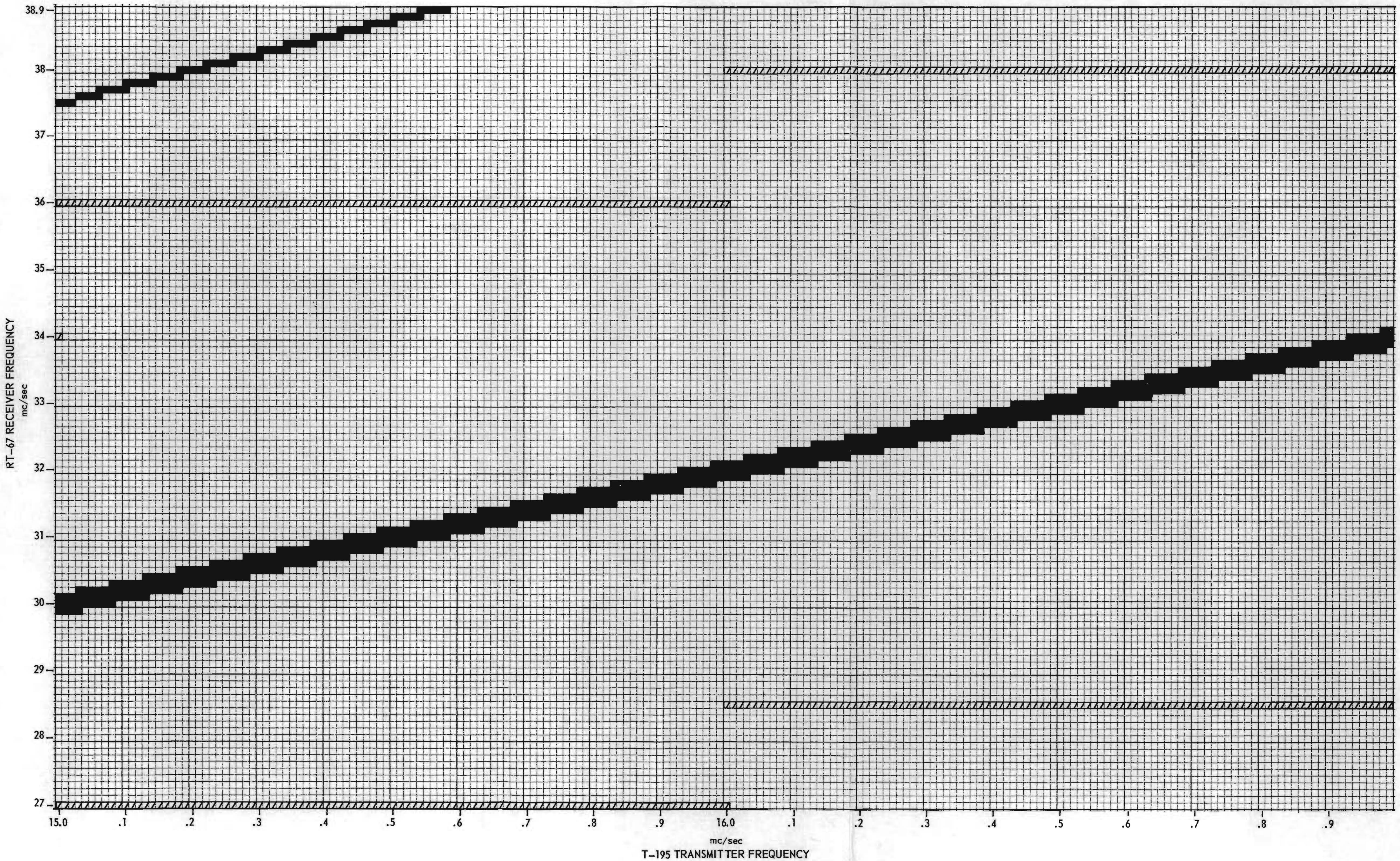

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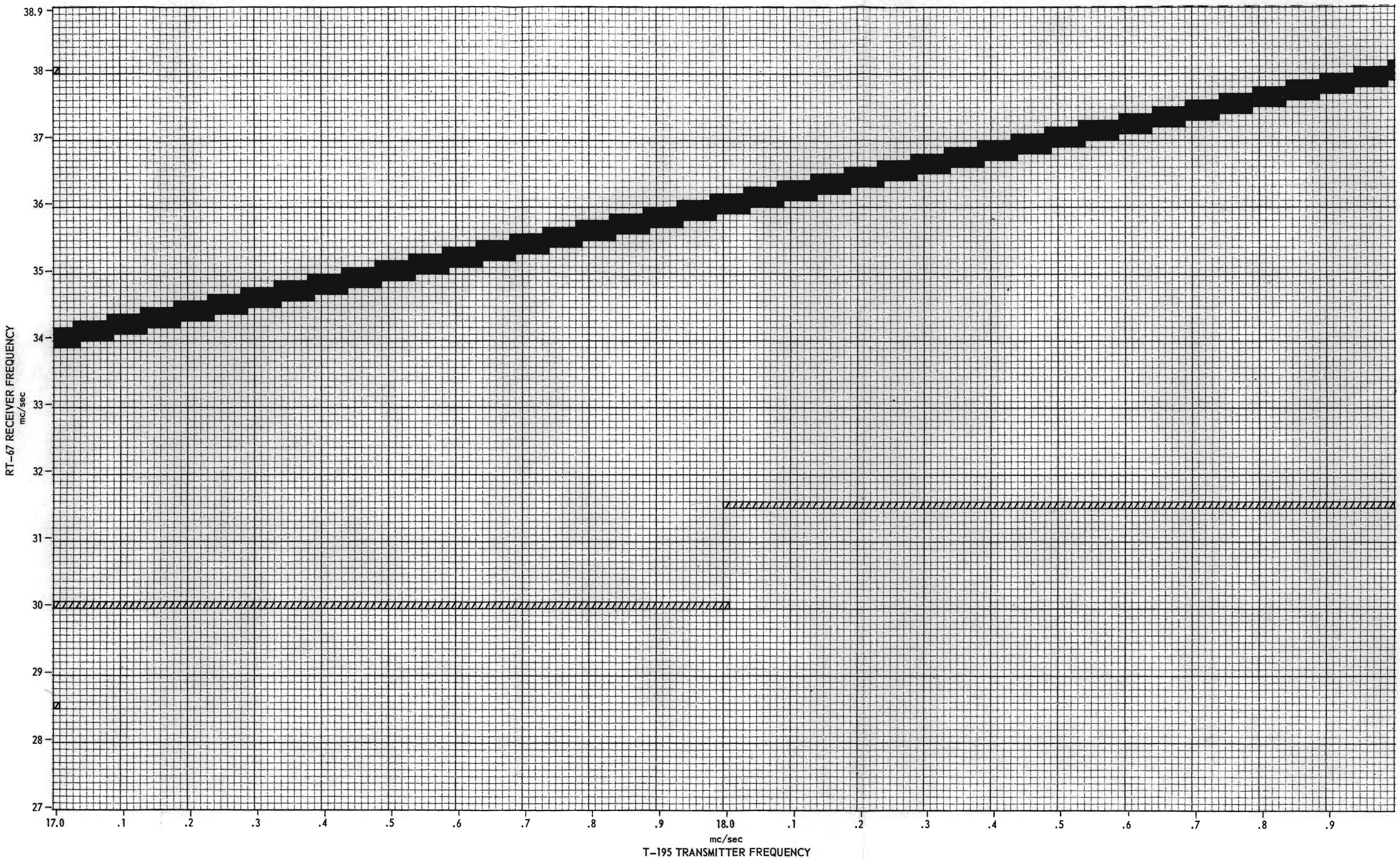

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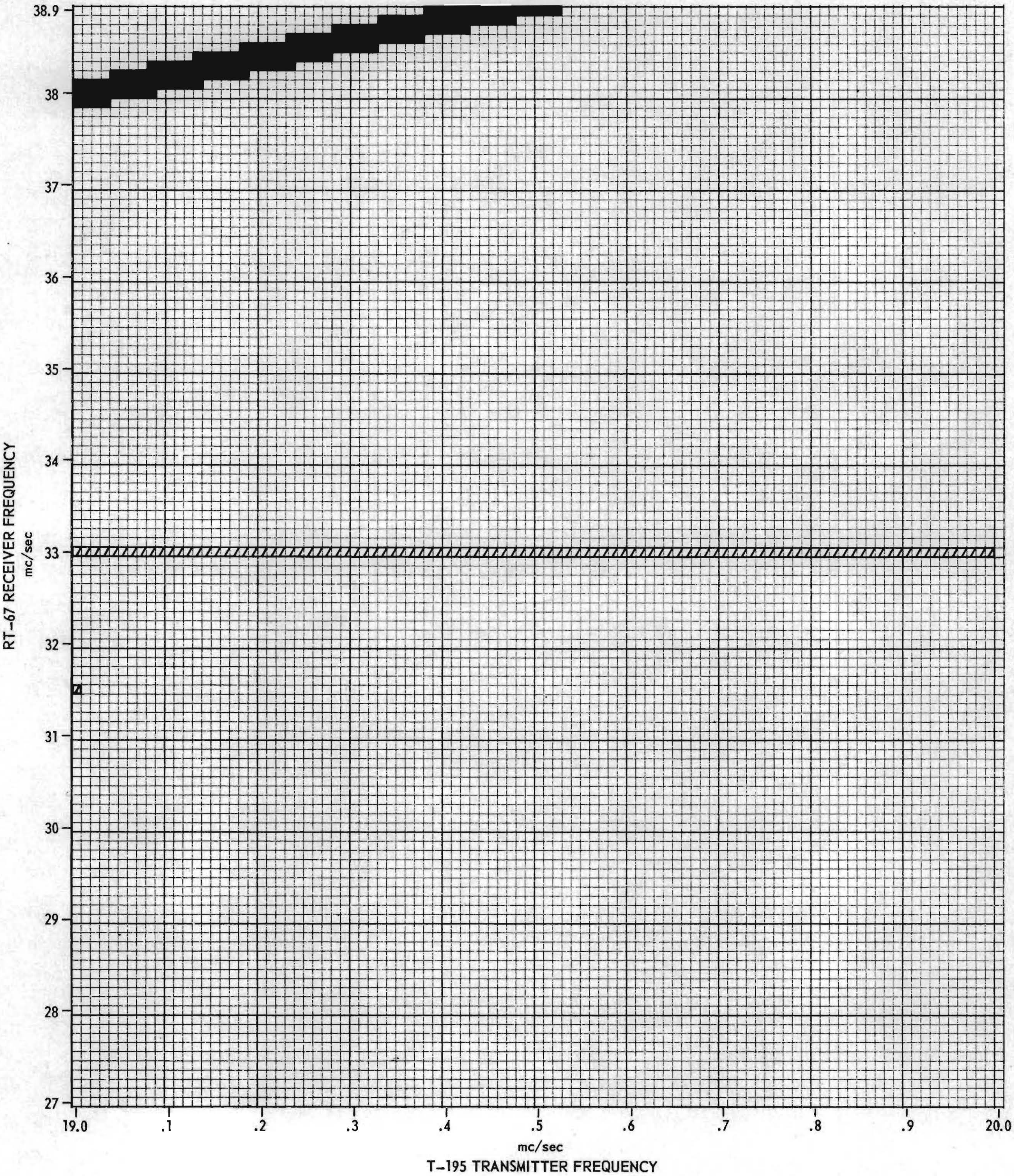

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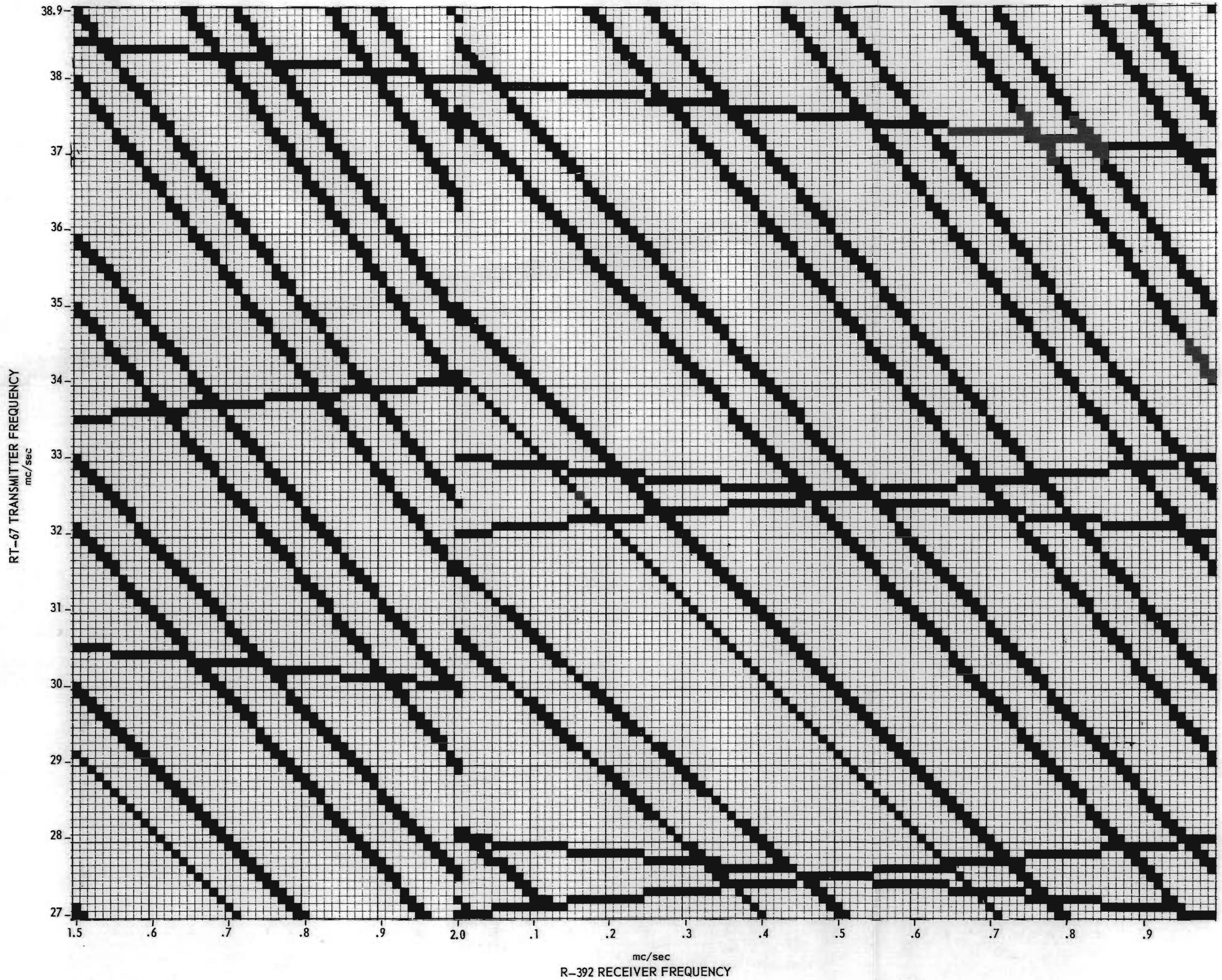
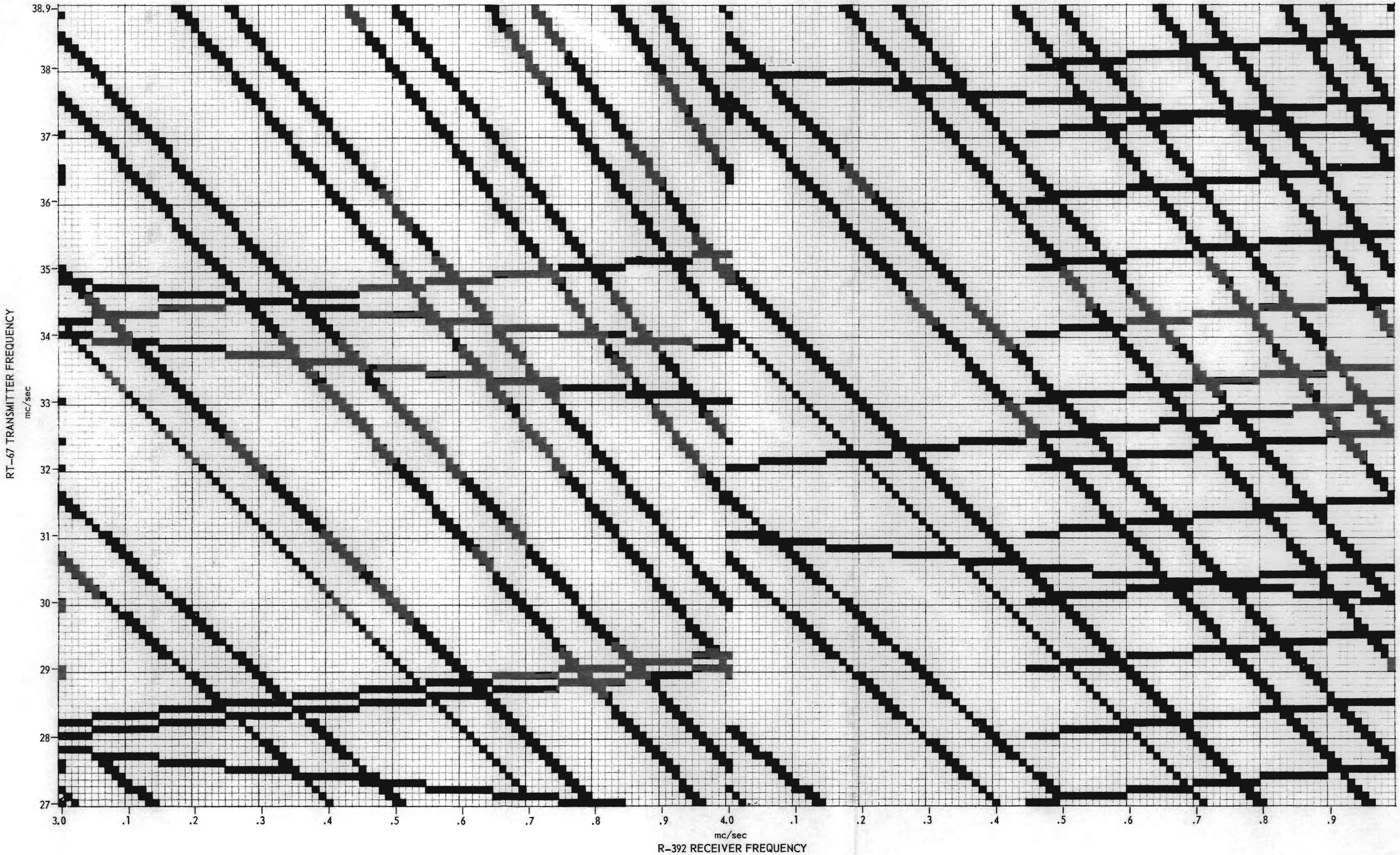


Figure 3. Mutual Interference Chart for the RT-67 Transmitter -- R-392 Receiver Combination.



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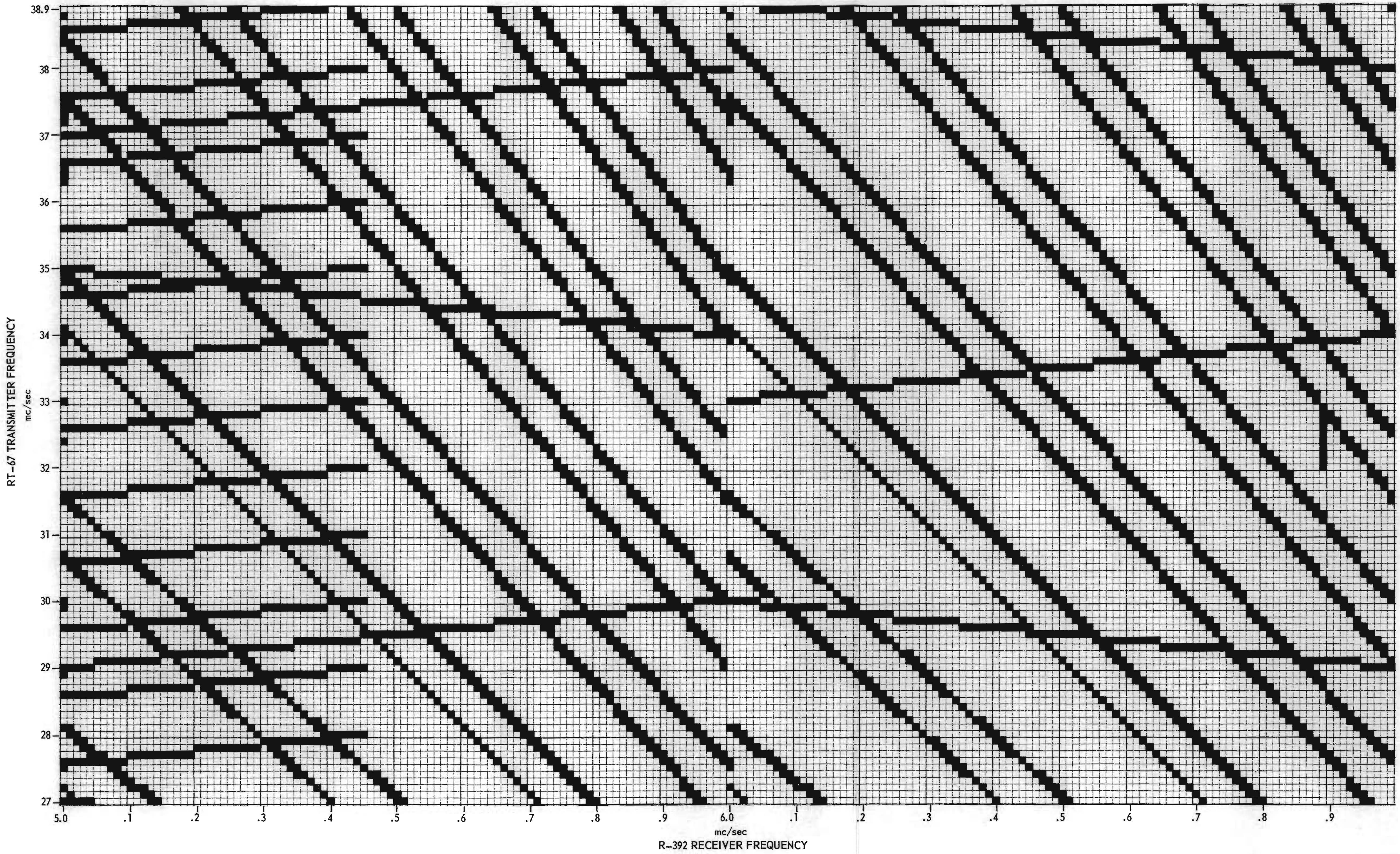

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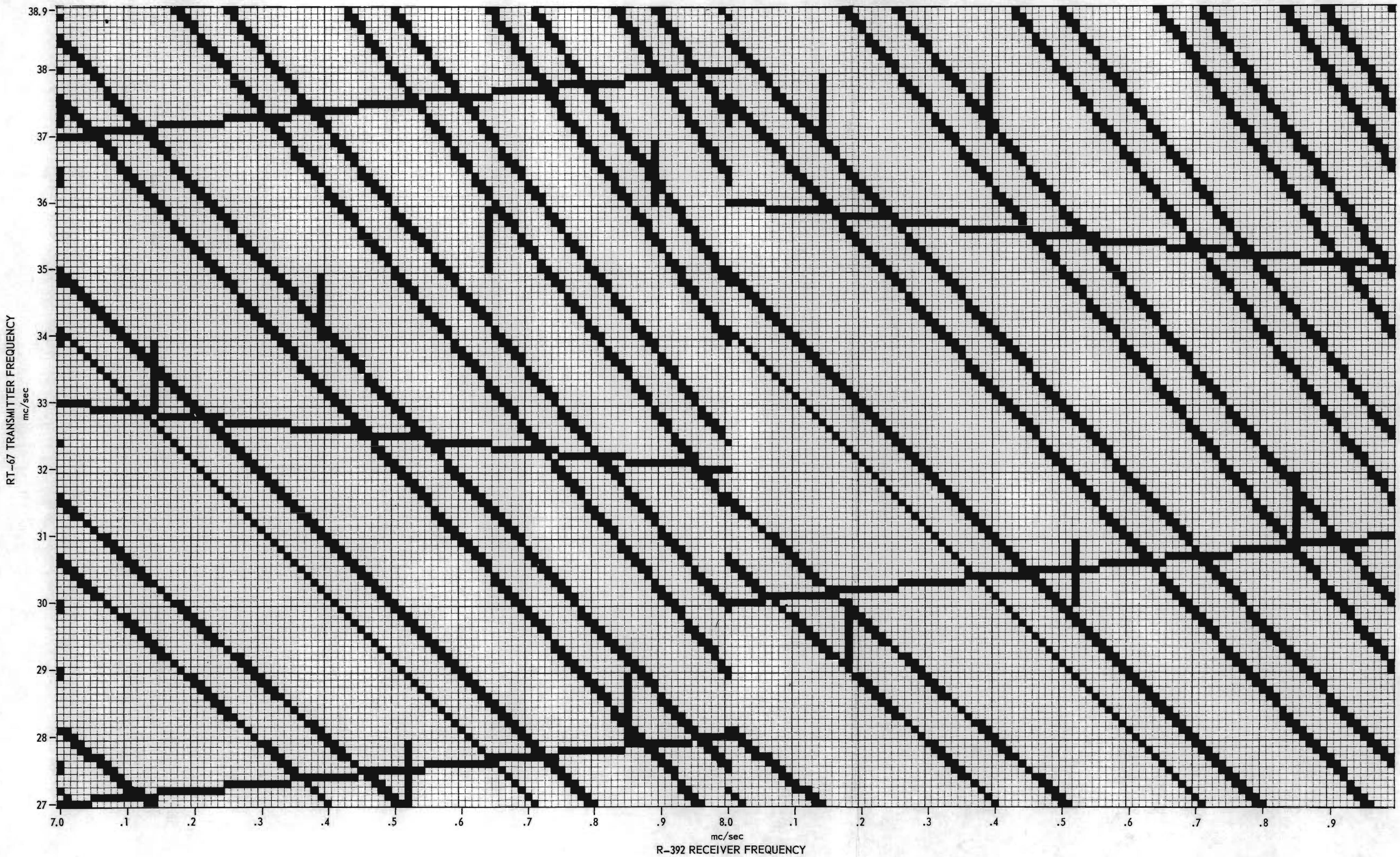

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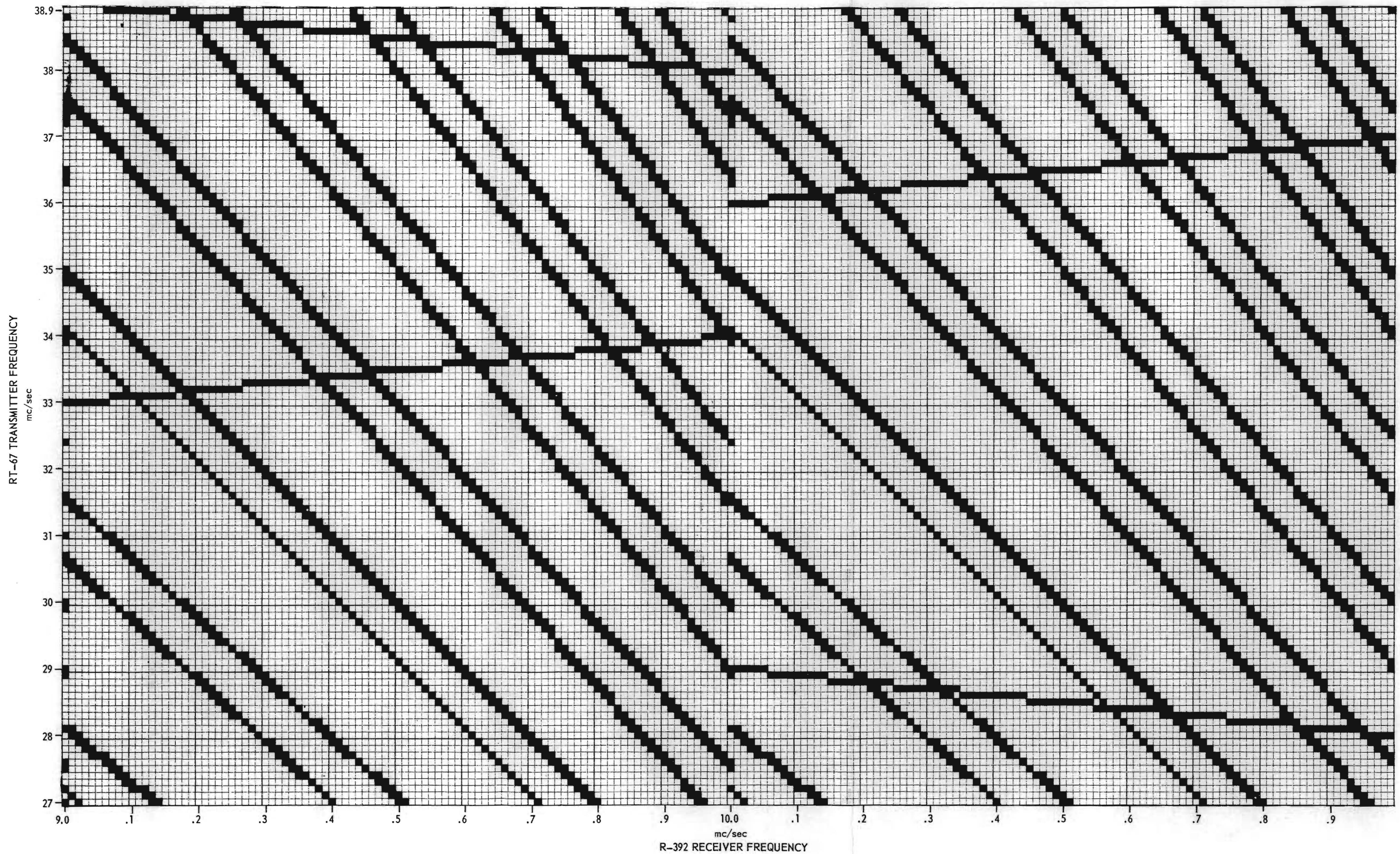

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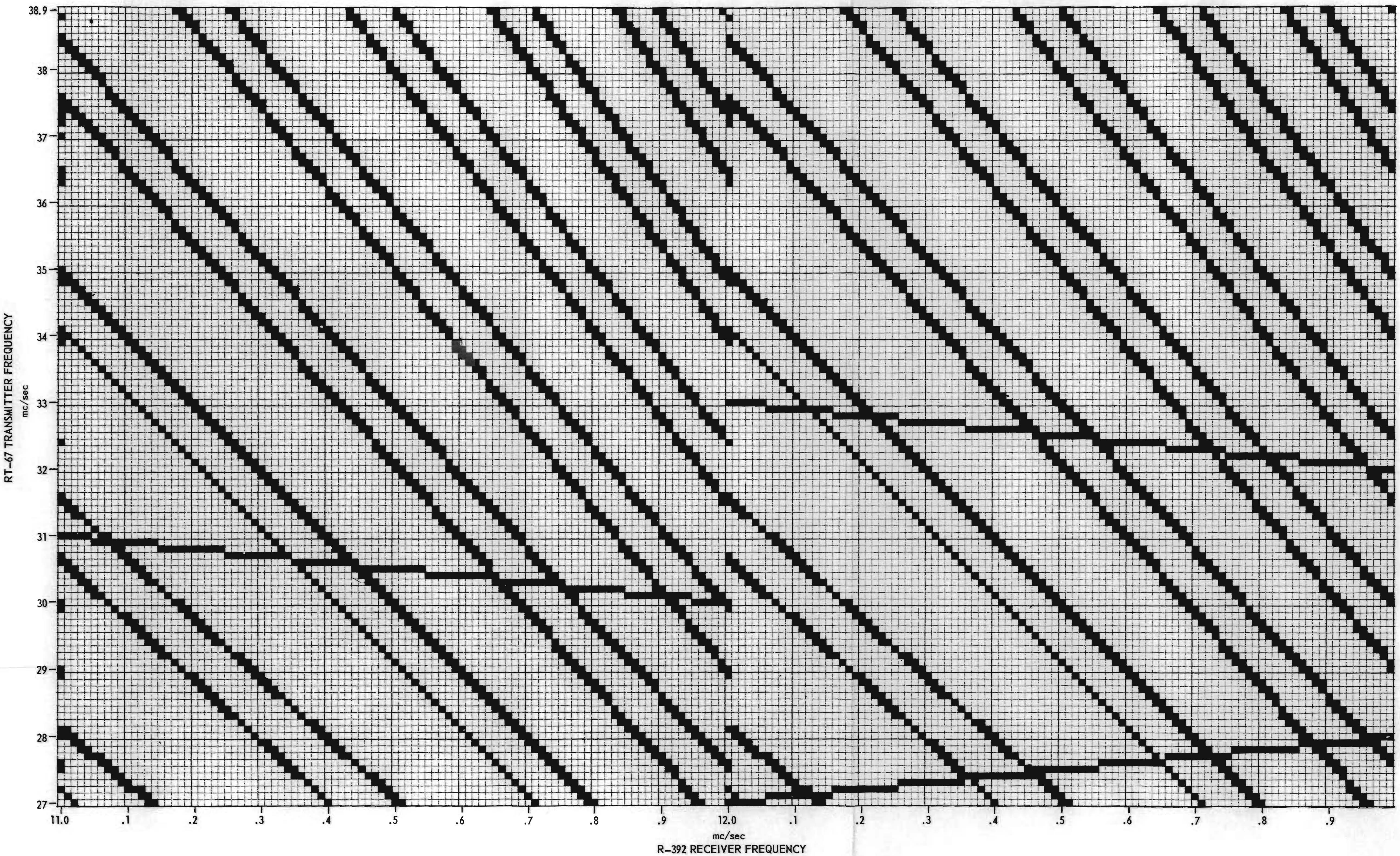

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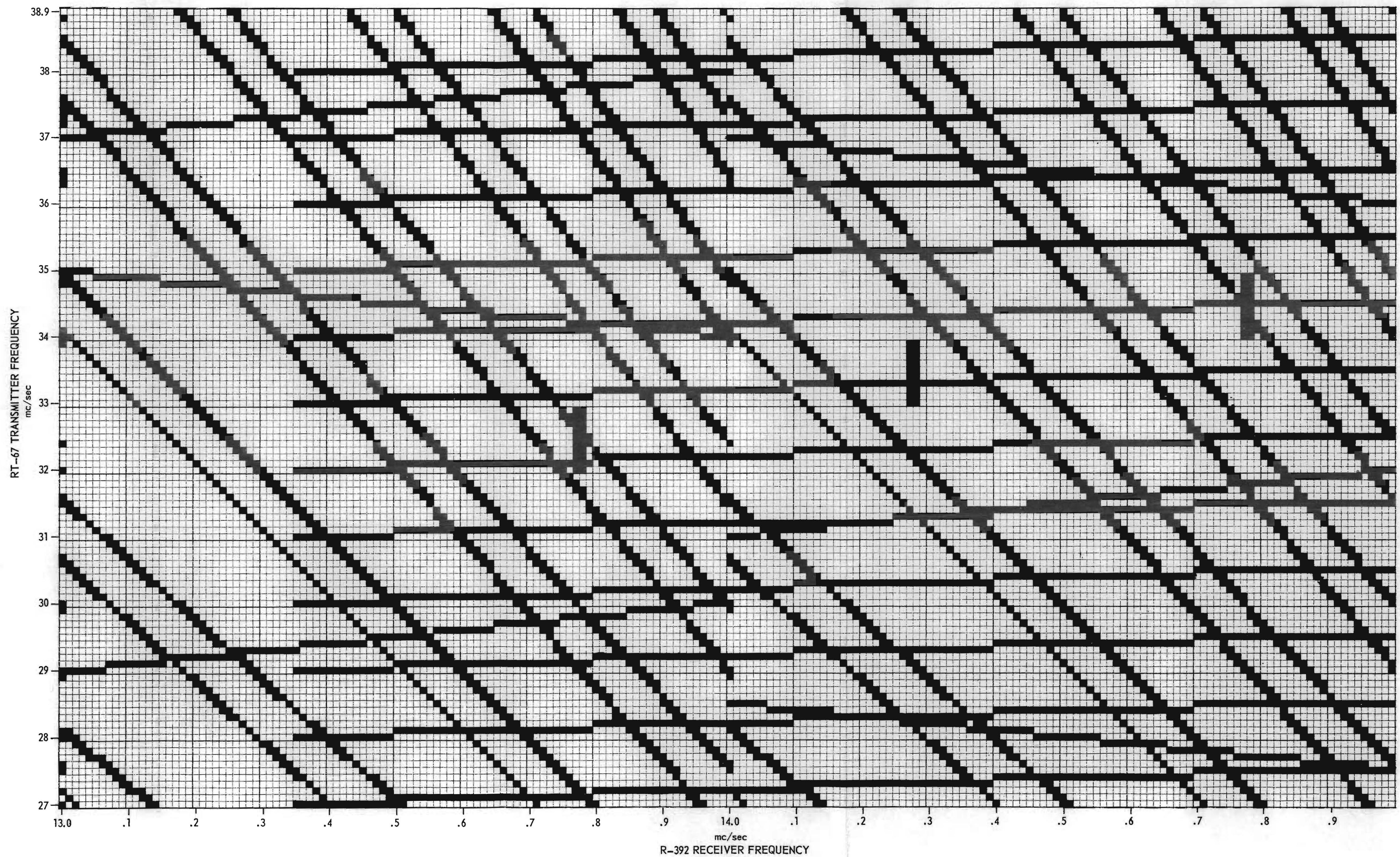

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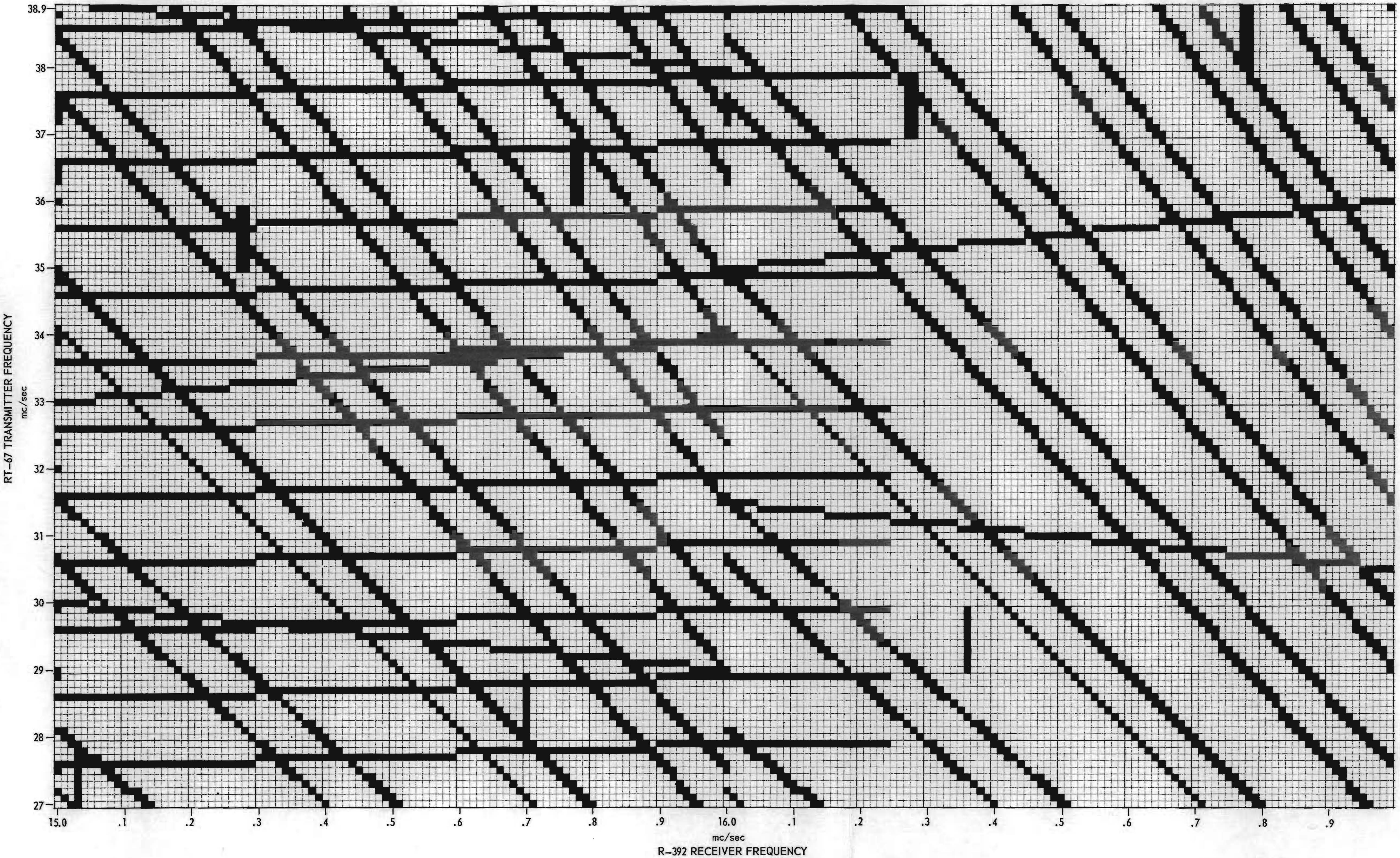

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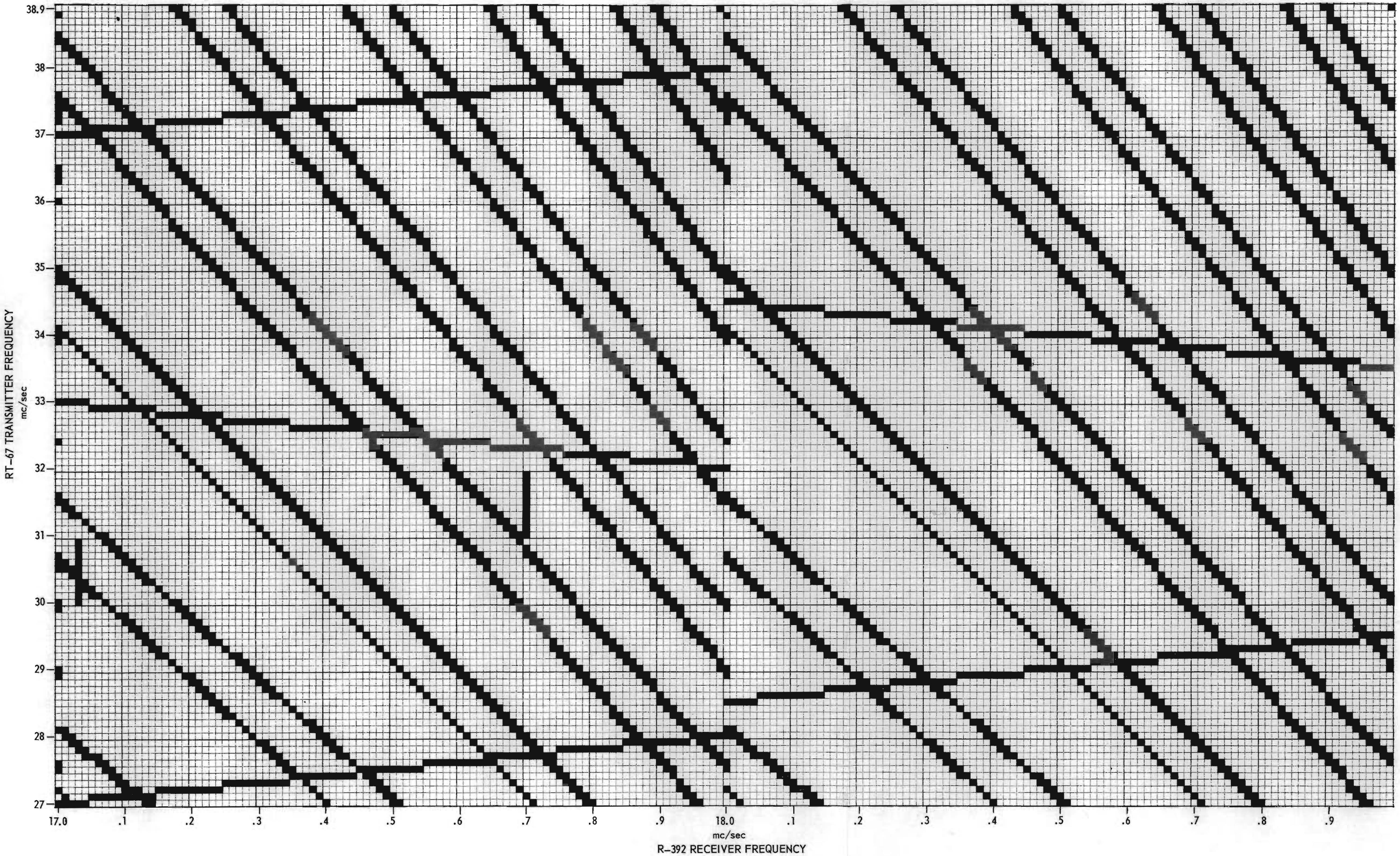

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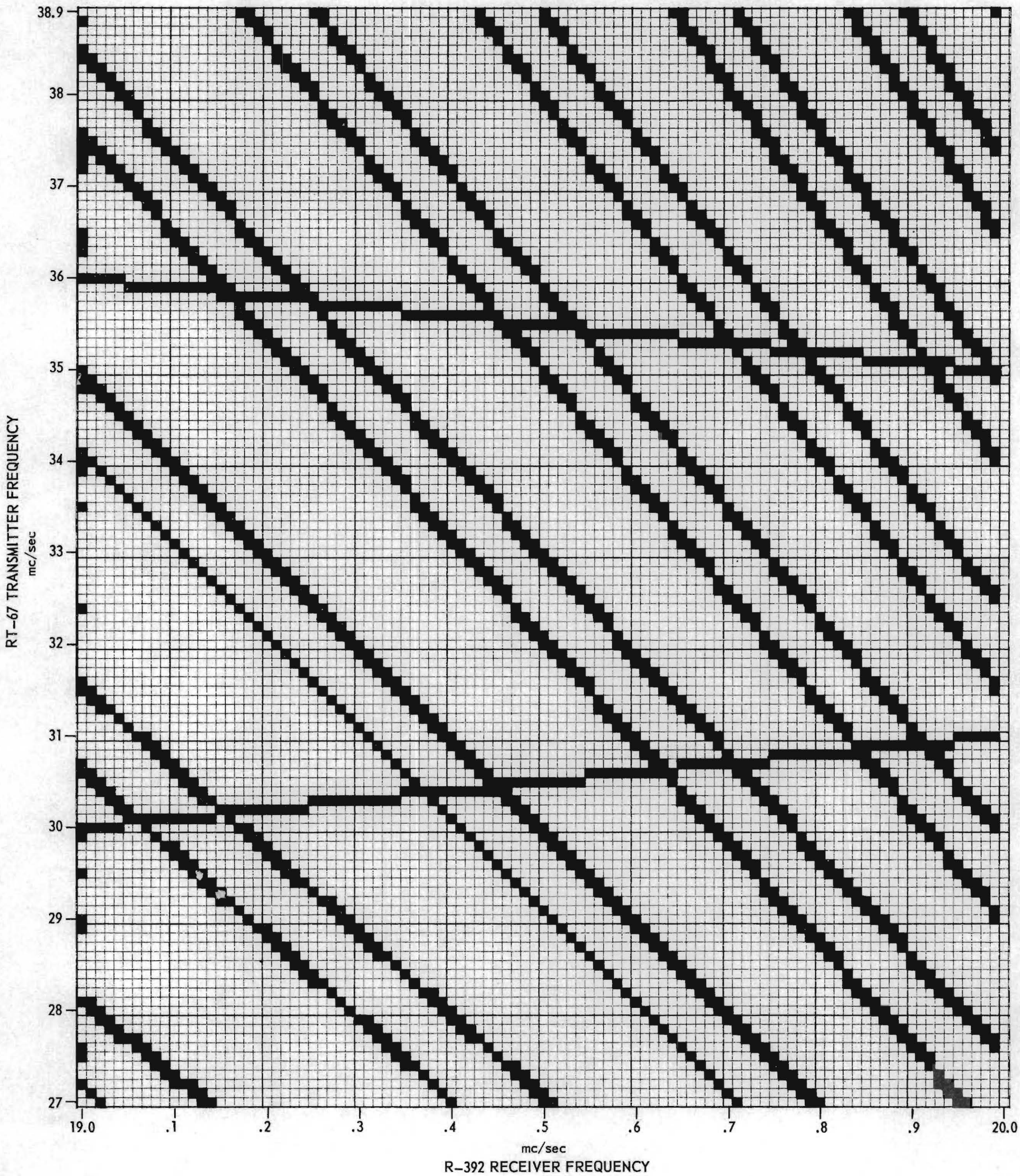

Figure 3 (Continued).

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